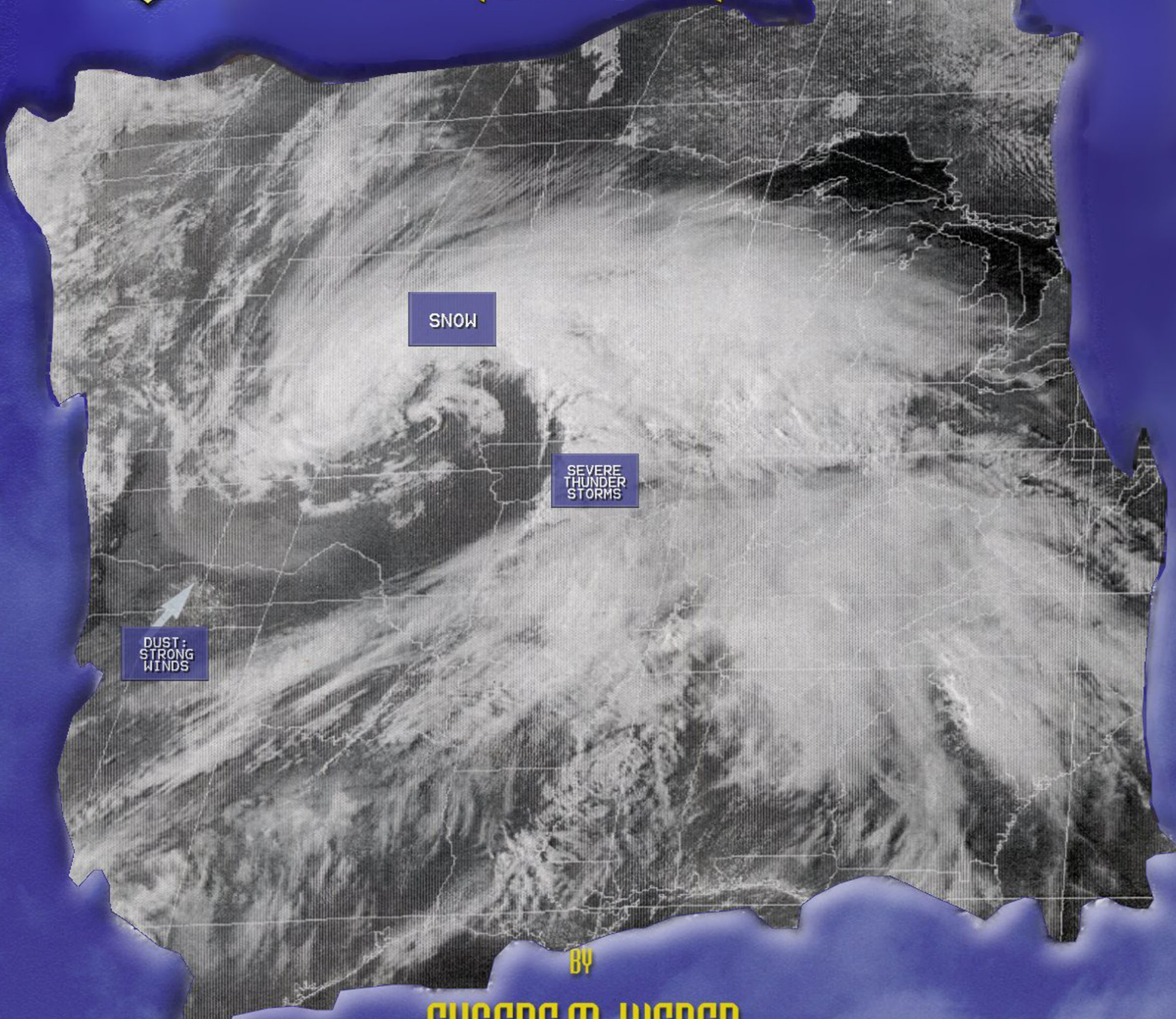
AFWA/TN-03/001
15 April 2003

SPRING REGIMES



BY

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REVIEW AND APPROVAL PAGE

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Note: All satellite pictures courtesy of Air Force Weather Agency's CONUS Severe Weather Unit and the National Oceanic and Atmosphere Administration (NOAA).

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13. Abstract: This technical note presents a back-to-basics approach to forecasting the transitional weather systems of spring. Although it is especially designed for new and inexperienced forecasters, it is an excellent review for all forecasters. As spring approaches, the CONUS becomes a battleground between cold winter-type airmasses and warm summer-type airmasses. This technical note presents synoptic patterns and regimes that routinely occur during the spring months. Synoptic pattern recognition remains one of the most important considerations when producing a forecast and will help in determining if forecast model guidance is "on track."

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TABLE OF CONTENTS

LIST OF FIGURES

PREFACE

This Technical Note is the third of four Forecaster Memos (FMs) being revised and updated with later model guidance and satellite images. Third Weather Wing (3 WW) originally published these FMs seasonal weather patterns in the early 1980s.

The information presented within this Technical Note is a culmination of weather experience that I have gained over 27 years as an Air Force weather forecaster, and after retirement, 16 years as a Civil Service Lead Forecaster in the Severe Weather Section of the AFGWC, and now AFWA's Production Floor.

Considerable knowledge was gained over the 16 years in the Severe Weather Section while observing weather conditions across the continental United States in preparation of the Military Weather Warning Advisories (MWAs) and also the issuance of Point Weather Warnings (PWWs). Certain weather patterns (regimes) for each season routinely occurred. A seasoned forecaster can spot evolving weather events across the country using analyses, satellite imagery, and model guidance.

The information that will be presented pertains to analyses, satellite interpretation and empirical rules. Some empirical information was extracted from my 3 WW publications: *Gulf Moisture Advection*, *Major Midwest Snowstorms*, *Satellite Interpretation*, and *Freezing Precipitation*. Some of the information dates back to the 1970s. However, "weather is weather," and events that occurred 30 years ago will repeat and repeat into the future. New methods and equipment to help forecasters have changed dramatically through the years. There has been an explosion of auxiliary weather information within the past few years through the Internet. Much weather data is available through the National Weather Service and many universities.

Very little model forecast data will be presented. The intent behind the absence of model guidance is to show that forecasters can produce short-term forecasts on their own by analyzing charts and interpreting satellite data. As mentioned above, there is so much model data available that one can become confused as to which product is best. Forecasters who become comfortable in analyses and satellite interpretation will have little trouble in initializing the zero hour model packages. The empirical rules that will be presented have been developed from many case studies throughout the years. These rules are intended as tools for synoptic pattern recognition of the potential for spring storm regimes and their associated weather.

This Technical Note was written in a common sense "back-to-basics" approach and has been especially designed for new and/or inexperienced forecasters. Also, it should be an excellent season review for all forecasters. The Technical Note is basically composed of synoptic patterns and regimes that routinely occur during the spring months. Although spring officially begins in the third week of March and continues through mid-June by the calendar date, I have included most weather information and case examples for spring regimes from mid-March through the end of May. By the beginning of June, most CONUS locations are experiencing the onset of summer conditions. Synoptic pattern recognition is still one of the most important considerations when producing a forecast and will help in determining if model guidance is "on track." Hopefully, I believe this Technical Note will help forecasters for years to come, regardless of any new numerical model improvements and/or new systems that will come on line.

ACKNOWLEDGMENTS

Special acknowledgment goes to Air Force Weather Agency's Commander and senior staff for funding and allowing me to continue part-time writing and publishing Technical Notes (after Civil Service retirement). This part-time position is managed through Science Applications International Corporation (SAIC).

Very special thanks go to Master Sergeant Mike Brooks at AFWA's Technical Training Branch of Air and Space Science (DNTT) for the final editing and formatting, graphics support, and advice in getting this Technical Note ready at AFWA for final publishing at the Air Force Combat Climatology Center (AFCCC).

Very special thanks to Ms Patricia Mumford (AFWA/DNTT) for the final graphic support (coloring of illustrations) for AFCCC.

Special thanks to other DNTT personnel: MSgt Charles Elford, TSgt K.G. Smith, Mr. Mark Mireles and TSgt Randall Brooks for some of the graphic support.

Very special thanks to Technical Sergeant Gina Vorce of the AFCCC Publishing Team (AFCCC/DOPA), for her graphics support and final desktop publication.

Finally, I acknowledge my wife, Doris, for her continued understanding of my interest in my profession, even after retirement.

EUGENE M.WEBER

Chapter 1

INTRODUCTION

For Air Force Weather (AFW) forecasters, a *regime* is defined as "a specific synoptic and/or mesoscale weather pattern that affects the local weather at a particular location." Weather occurs at all scales of motion; however, dominant local effects are usually associated with the synoptic scale weather pattern (highs, lows, fronts, etc.). In many cases, significant local effects are associated with mesoscale patterns (low-level jets, cold air damming, land/sea breezes, etc.).

The following regimes and patterns are intended to remind forecasters of changes during the winter to summer transitional period.

To most forecasters, the transitional period from winter to summer is the most exciting and challenging time of the year; the spring season offers rapid changes from day-to-day. The slower-moving, large-scale trough-and-ridge systems of winter, maintained by minimal solar insolation and strong land-water contrasts, are replaced during spring with increasing zonal flow patterns. Smaller-scale features within the upper flow assume more importance. Solar insolation, moisture and instability increase through the period. Short wave troughs, associated with the northward-moving polar jet, trigger frequent cyclogenesis across the CONUS. During March and April – a period of rapidly-changing conditions – continental polar air struggles to keep its winter's hold, but finally relents and moves back into Canada. Increasing thunderstorms, including severe thunderstorms and tornadoes, along with rain, snow, freezing precipitation, fog and perhaps dust storms may occur simultaneously with each major storm system over the central CONUS, as illustrated in the cover figure.

UPPER LEVELS

General Circulation. The general circulation begins to weaken in March and the strong westerlies of winter show an overall northward migration.

Polar and Subtropical Jets. At the onset of spring, the polar jet generally lies in its winter position across the southern CONUS as shown in Figures 2-1 through Figure 2-2. (These illustrations are several days prior to the arrival of the vernal equinox). Note: Further discussions on jet stream identification on satellite images are included in *Winter Regimes*.

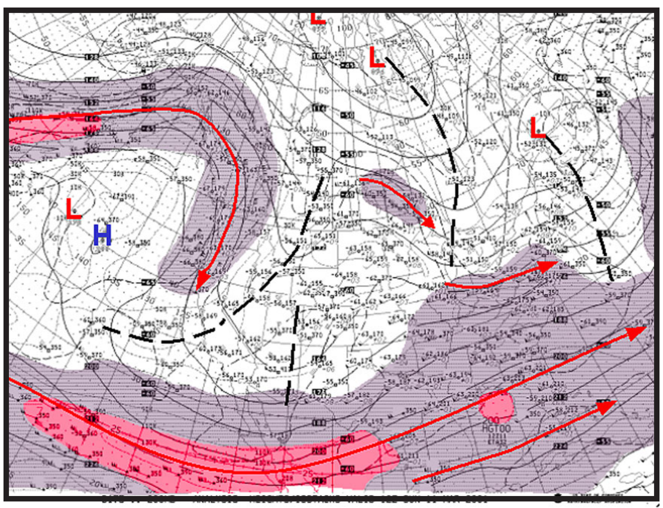

Figure 2-1. 200 mb 1200Z/11 March 2001. Several shortwave systems are shown within a longwave trough over the western CONUS.

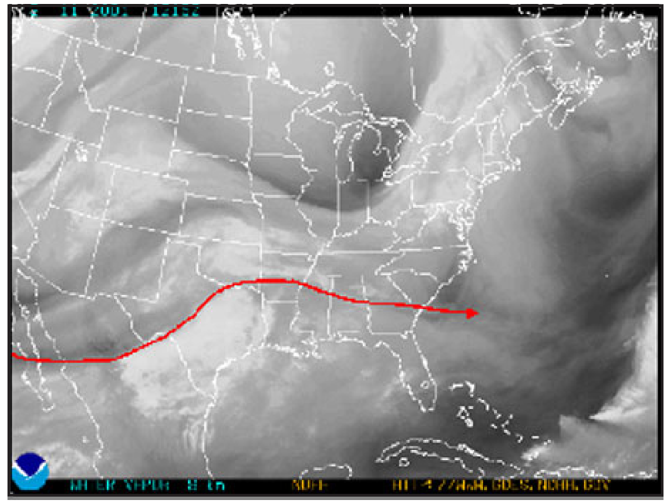

Figure 2-2. GOES E-WV 1215Z/11 March 2001. Approximately same time as Figure 2-1. Several jet branches are noted.

The polar jet gradually moves northward during April and May, as shown in Figures 2-3 through 2-5. In Figure 2-5, the subtropical jet can be seen across the bottom of the picture. The polar jet is noted further to the north. By late May, the subtropical ridge has drifted northward across the southern CONUS.

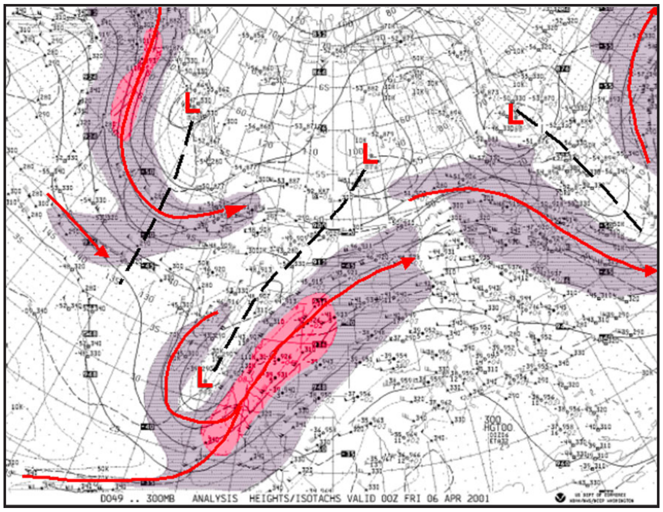

Figure 2-3. 300 mb 0000Z/6 April 2001. Typical jet steam pattern associated with a western CONUS upper low.

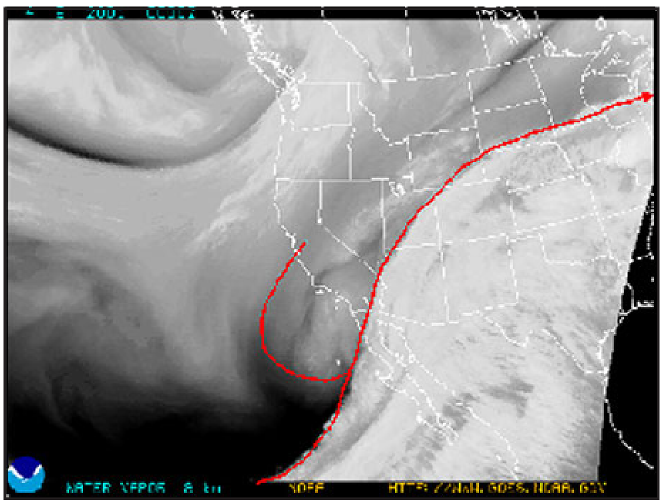

Figure 2-4. GOES W Water Vapor 0000Z/6 April 2001. A pronounced subtropical jet stream has lifted northward over the southwestern CONUS and the Great Plains. Several lower-level polar jet streams can be seen over the western CONUS and the Pacific Ocean. Related to Figure 2-3.

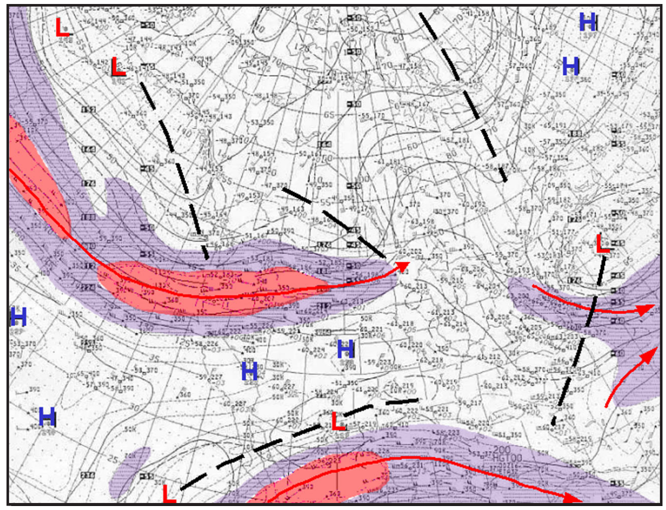

Figure 2-5. 200 mb 0000Z/16 May 2001.

By the onset of summer, lies across the northern CONUS and into Canada (Figures 2-6 through 2-8). Figures 2-7 and 2-8 illustrate typical early-summer conditions across the CONUS.

The polar jet continues to lift northward during June as shown in Figures 2-6 and 2-9. The satellite photo, Figure 2-8, shows frontal, sea breeze, air mass, and orographic convection across the CONUS.

In Figure 2-9, a few days into summer, the main polar jet has lifted into Canada. Subtropical ridging extends across a large area of the CONUS. Upper shortwave troughs (buried in subtropical ridging) are generally weak but still can produce significant convection and rainfall. The subtropical jet becomes the dominant jet stream across the southern CONUS towards the end of spring.

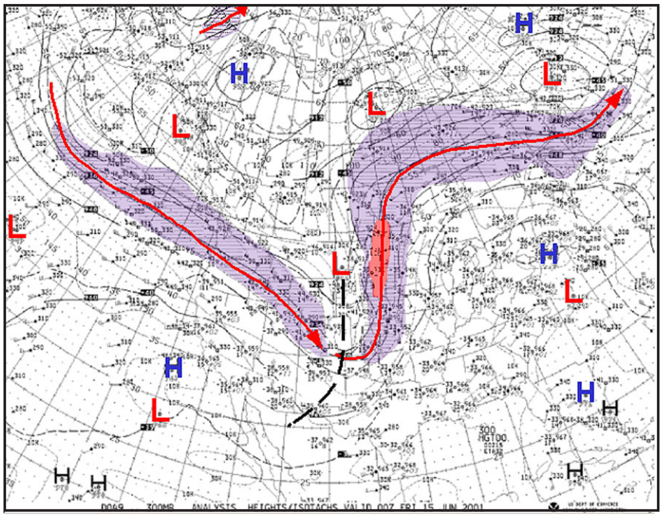

Figure 2-6. 300 mb 0000Z/15 June 2001.

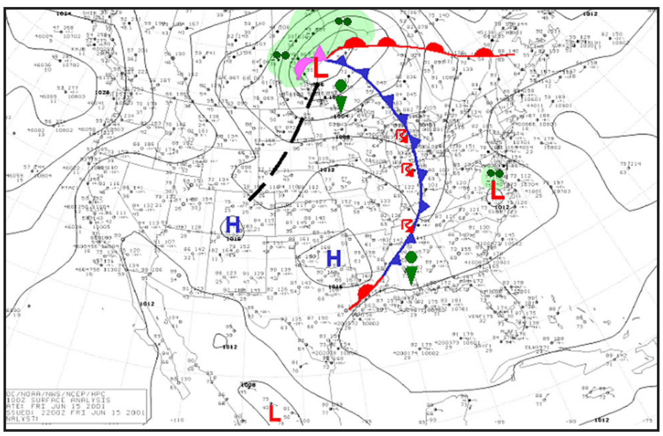

Figure 2-7. Surface 2100Z/15 June 2001. Signs of summer: Low pressure systems move across the northern CONUS and Canada, weak isobaric gradients, increased surface heating and moisture along with instability initiates the summer regime.

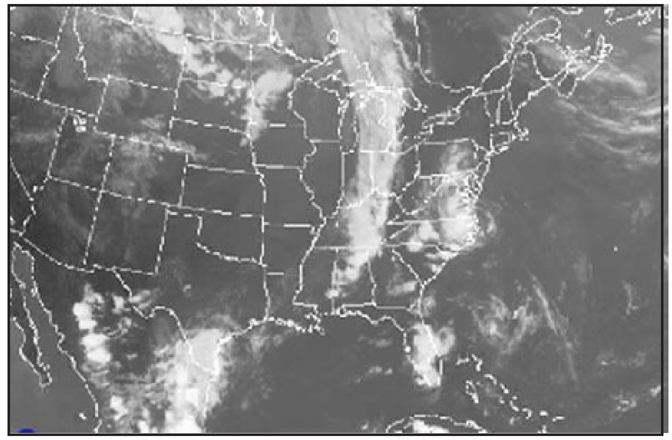

Figure 2-8. GOES E IR 2345Z/15 June 2001. This late afternoon image, at the onset of summer, reveals mostly convection across the CONUS. Sea breeze convection is shown over Florida, frontal convection over the Carolina region, Great Lakes/Ohio Valley region and the northern Great Plains. Gulf moisture is evident over southern Texas and orographic thunderstorms have begun over the Mexican mountains.

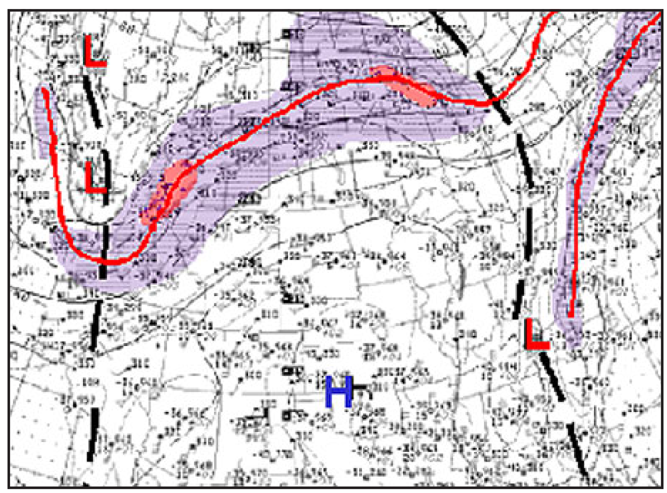

Figure 2-9. 300-mb 0000Z/25 June 2001.

Upper Levels

The large-scale meridional troughs and ridges of winter that generally prevail over land regions (such as shown in Figure 2-10) become less frequent in April, as short waves become the dominant regime. Long wave trough systems are likely through the end of spring as depicted in the May example in Figure 2-10a. Often these long wave troughs are located over the East and West Coast and adjacent cooler ocean areas as ridges build inland. Deep short waves during April may briefly resemble longwave troughs, as these systems move eastward.

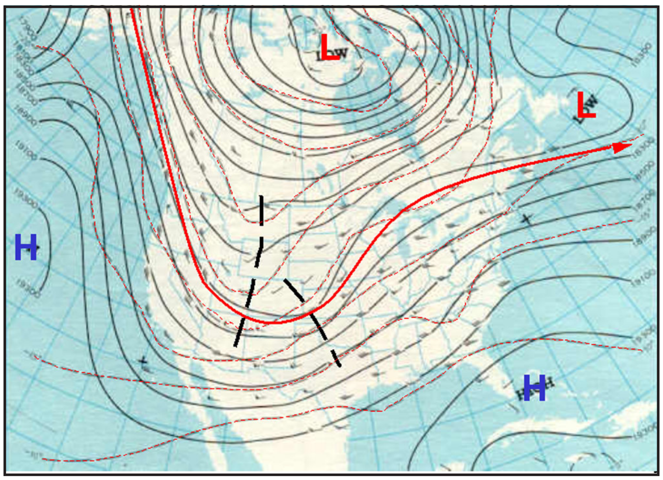

Figure 2-10. 500 mb 1200Z/1 April 1979.

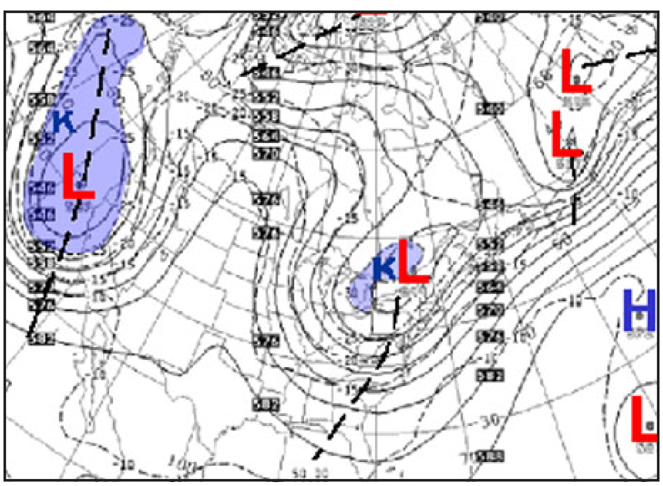

Figure 2-10a. 500-mb 1200Z/20 May.

Zonal Regimes (Short Waves). A shift to a zonal flow regime across the CONUS during spring will bring more Pacific short wave troughs across the CONUS as shown in Figures 2-11 through 2-13. During March and April, increased cyclogenesis within short waves tracking across the CONUS will produce more occurrences of surface low development from the Great Basin eastward to the East Coast. These zonal flow short waves are responsible for many spring storms over the CONUS and severe thunderstorm events east of the Rocky Mountains as will be shown throughout the rest of this Technical Note.

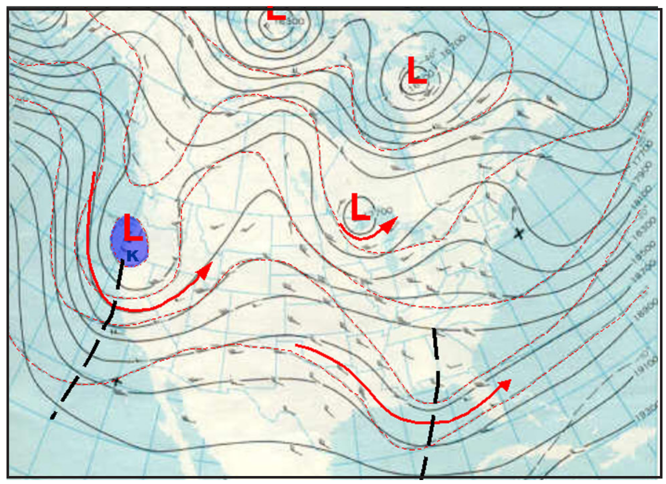

Figure 2-11. 500 mb, 1200Z/26 March 1981.

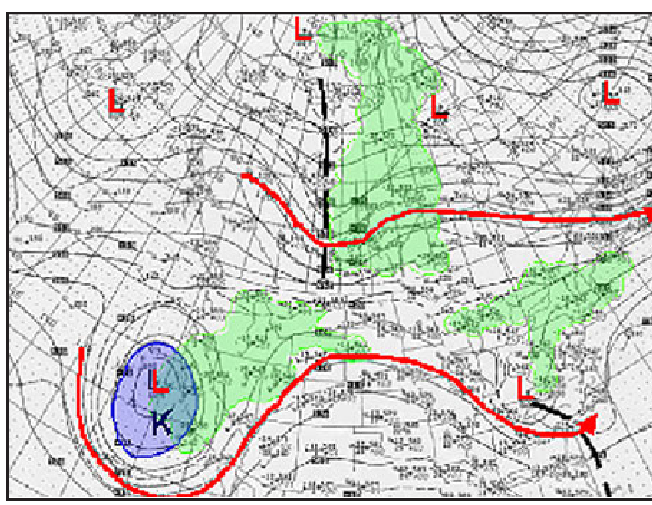

Figure 2-12. 500 mb 0000Z/18 April 2000.

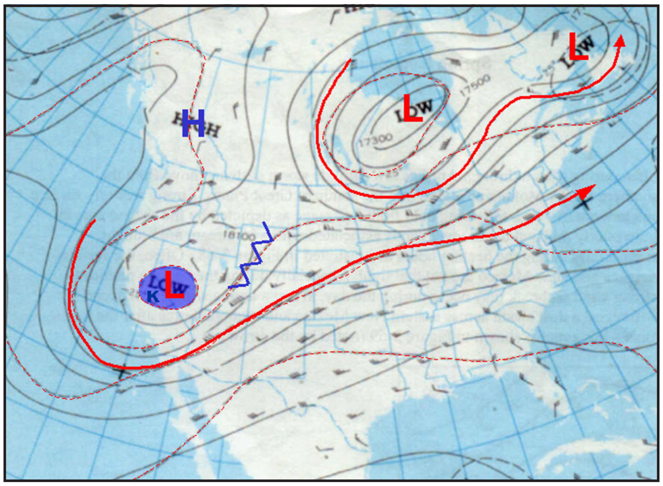

Figure 2-13. 500 mb 1200Z/11 May 1980. Closed low with strong jet stream support shown over the southwestern CONUS.

Cutoff Lows -Upper Levels. Starting in late April and continuing through May, lows sometimes tend to break away to the south of the main upper-level westerlies, and become cut off. Cutoff lows appear more often during the transitional periods of spring and autumn because the main belt of westerlies still lies across the northern CONUS and Canada. Occasionally, short wave trough systems moving through the westerlies dig far enough southward into the CONUS so that conditions favorable for a closed low circulation are established (Figure 2-14). While the main jet stream will lie to the north, a weaker jet may appear within the cutoff low circulation.

While common during spring, cutoff lows may occur over any area of the CONUS at any time of the year. They seem to favor the area over the southwestern CONUS and adjacent ocean areas (Figure 2-14). These systems often move slowly or are stationary, and it is not uncommon for one to appear continuously on the upper air charts for a week or more. Cutoff lows sometimes appear as a result of blocking patterns and may remain nearly stationary for days until the block has broken down (see Figures 2-14 and 2-15). The frequency of occurrence for the cutoff low regime peaks in May.

Don't become confused between the closed low, Figure 2-13, and the cutoff low as in Figure 2-14. Cutoff lows are not associated with the primary westerly (and polar jet) flow as closed lows are. Cutoff lows, as an entity, have weaker jet stream associated with them. Locations affected by these stagnant systems may experience the same weather conditions for several days in a row. Attempting to forecast the overall movement of a cutoff low is a challenge.

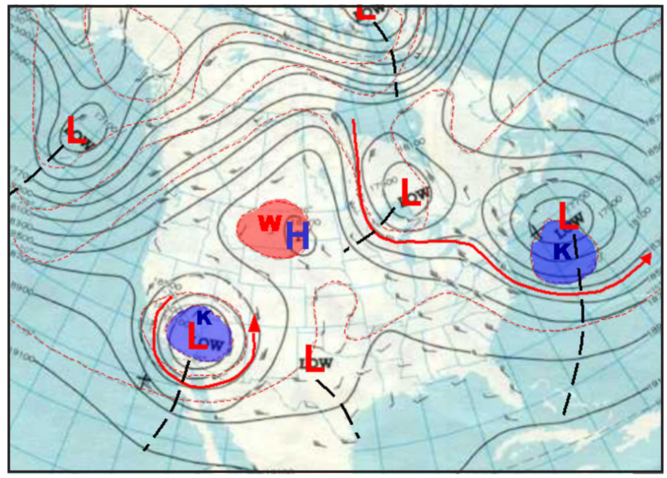

Figure 2-14. 500 mb 1200Z/23 April 1980. Cutoff low shown over the southwestern CONUS.

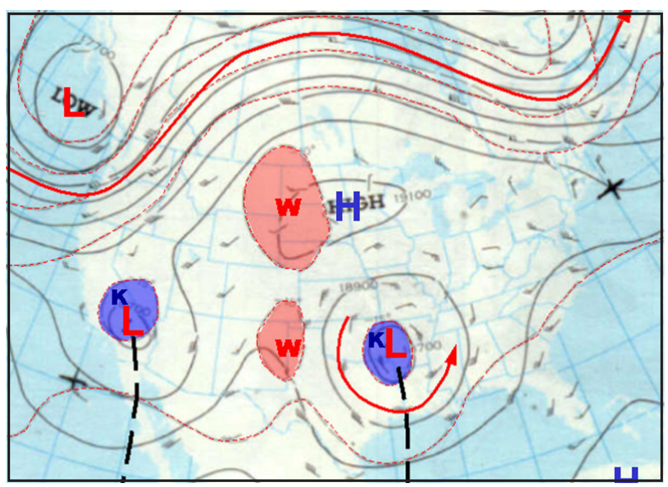

Figure 2-15. 500 mb 1200Z/22 May 1980. Polar jet lies mostly in Canada. Subtropical ridging and cutoff lows prevail over the CONUS.

Cutoff Lows- Surface. The surface weather associated with these systems varies and is dependent upon the cutoff low's area of development. Generally the surface gradients are weak (Figure 2-16) and a low may not appear on the surface in association with the upper low (see Figure 2-17). Heavy rains and flooding conditions may occur over the central and eastern CONUS for several days when a cutoff low moves into or develops over the south central CONUS. Due to the slow track of these systems, gulf moisture generally advects into these systems over a long period of time.

Another cutoff low example that occurred over the eastern CONUS is shown in Figures 2-18 and 2-19.

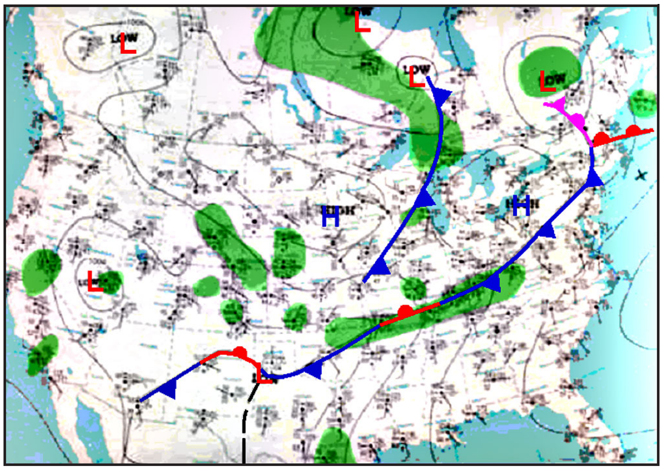

Figure 2-16. Surface 1200Z/29 April 1980. There is little evidence of a surface low-pressure system over the eastern CONUS that should be associated with the upper low depicted in Figure 2-17.

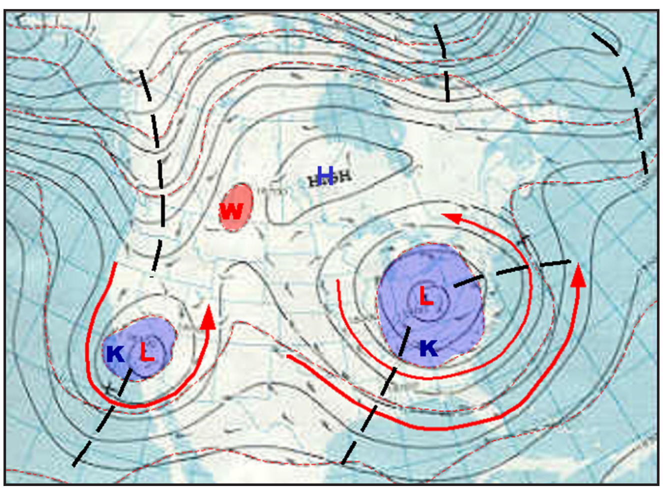

Figure 2-17. 500 mb 1200Z/29 April 1980. Two cutoff lows are shown over the CONUS with a closed high over southern Canada. The cutoff low shown over the eastern CONUS was stationary for several days. **NOTE:** Another cutoff low is shown in Figure 2-19 over the central and eastern CONUS twenty-one years later.

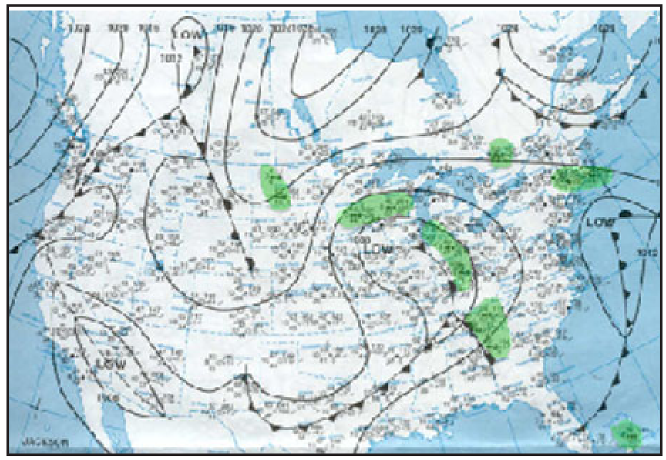

Figure 2-18. Surface, 1200Z/24 May 2001.

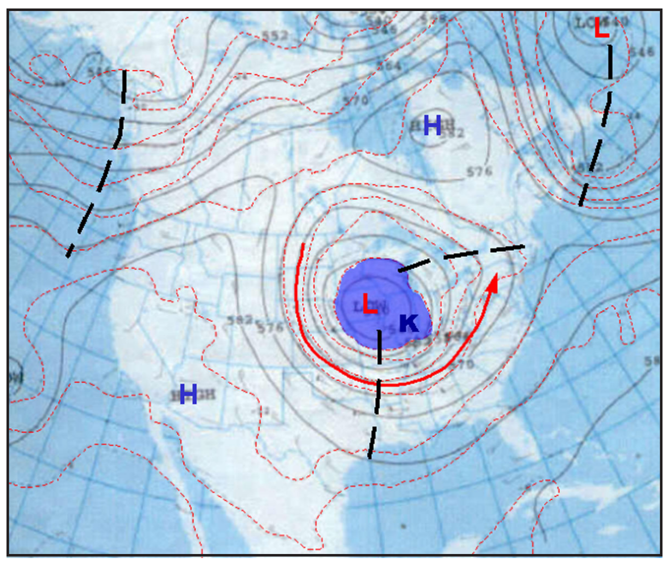

Figure 2-19. 500 mb 1200Z/24 May 2001. This low formed over Minnesota on May 22 and became disconnected (cutoff) from the main westerlies on May 23. The cutoff low remained over the eastern CONUS until May 28 when it finally moved into southeastern Canada.

In late May, the subtropical ridge drifts northward and becomes established during June as a dominant summer feature (Figures 2-20 and 2-21). Major trough systems persist over the cooler ocean areas; short wave systems move across the northern CONUS and Canada.

Figure 2-22 shows an early summer 300 mb chart. In this example, the polar jet stream lies across northern Canada. Weaker winds, contours and thermal gradients and pressure centers dominate the entire CONUS.

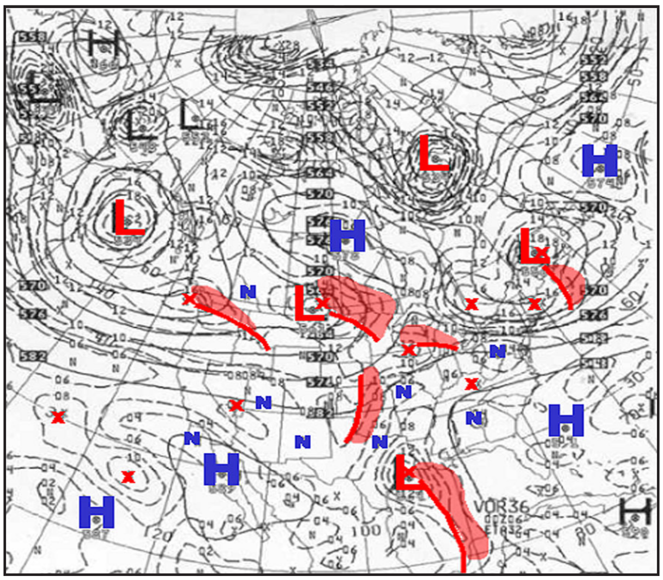

Figure 2-20. ETA 36HR HEIGHTS/VORTICITY. 0000Z/6 June 2001. Subtropical ridging extends across the southern CONUS with a cutoff low shown between the two high cells.

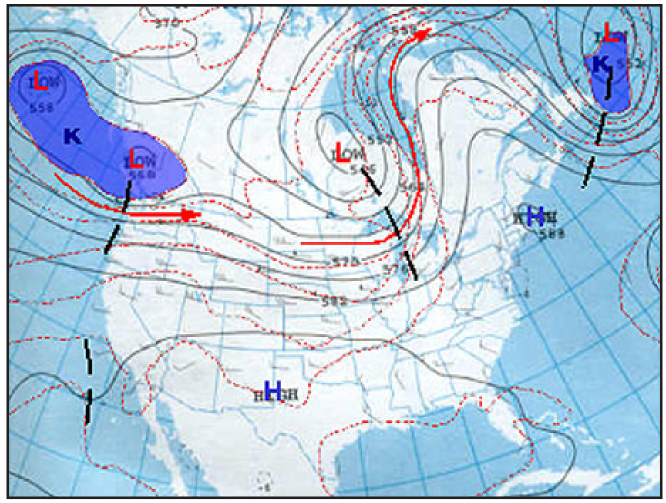

Figure 2-21. 500 mb 1200Z/16 June 2001. The subtropical ridge strengthens over the CONUS as the summer season begins.

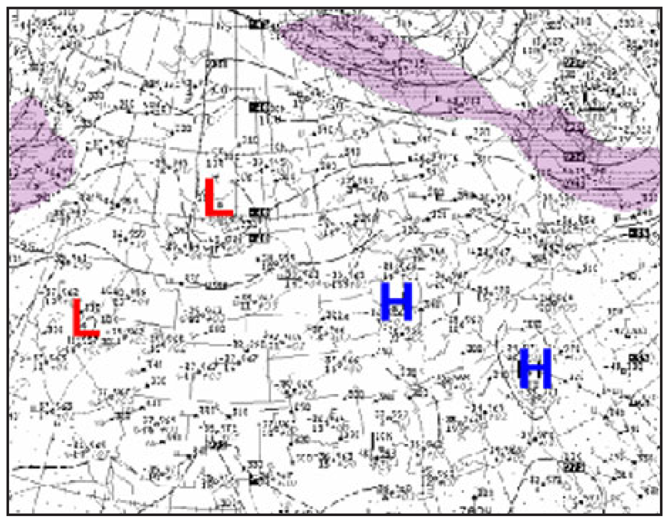

Figure 2-22. 300 mb 0000Z/25 June 2002.

WESTERN CONUS

Shortwave Troughs (Zonal Flow)

As mentioned in Chapter 2, Pacific shortwave troughs within zonal flow frequently track across the CONUS as shown in Figures 3-1 and 3-2. The figures depict shortwave activity during a four-day period.

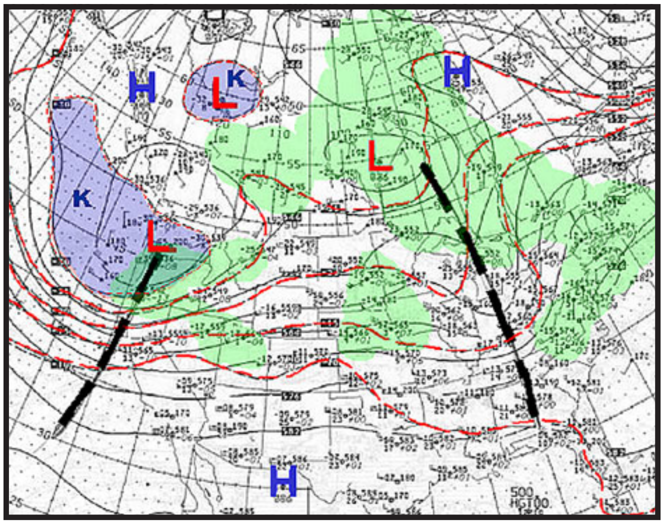

Figure 3-1. 500 mb 1200Z/10 May 2000. A zonal flow regime with two short waves extends across the CONUS.

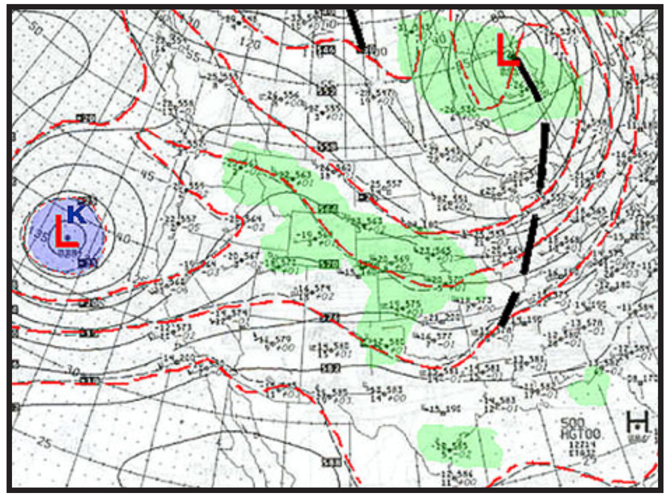

Figure 3-2. 500 mb 1200Z/14 May 2000. Another strong short wave is moving towards the West Coast.

Pacific Storm Tracks

Shortwave low pressure systems continue to be a threat over the western CONUS throughout the spring season. Figures 3-3 through 3-5 depict selected satellite images of eastern Pacific storm systems off the West Coast of North America. Figure 3-3, an early March event, shows a strong low located off the southern California coast. Storm tracks shift northward during spring, and by the onset of summer, are generally located over the Gulf of Alaska region.

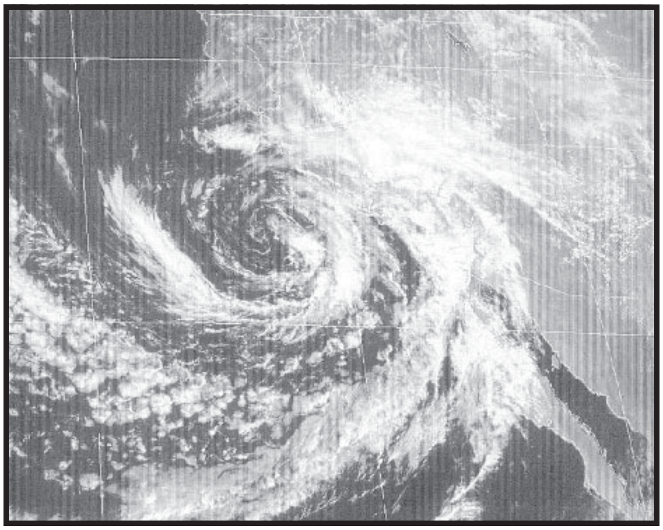

Figure 3-3. GOES-W VIS, 2000Z/6 Mar 2001.

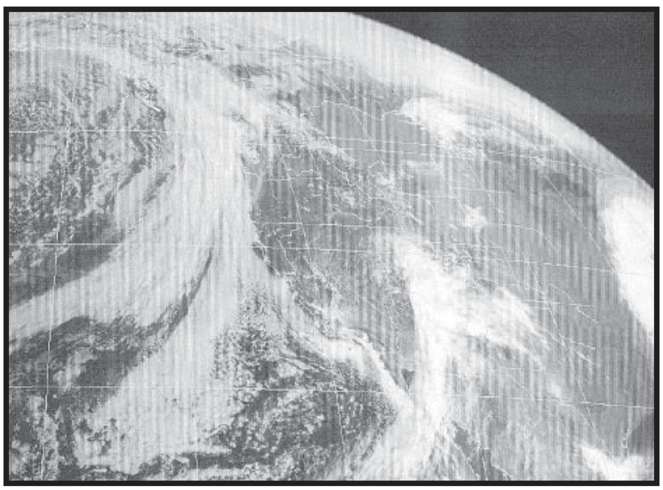

Figure 3-4. GOES-W VIS, 1615Z/21 April 2001.

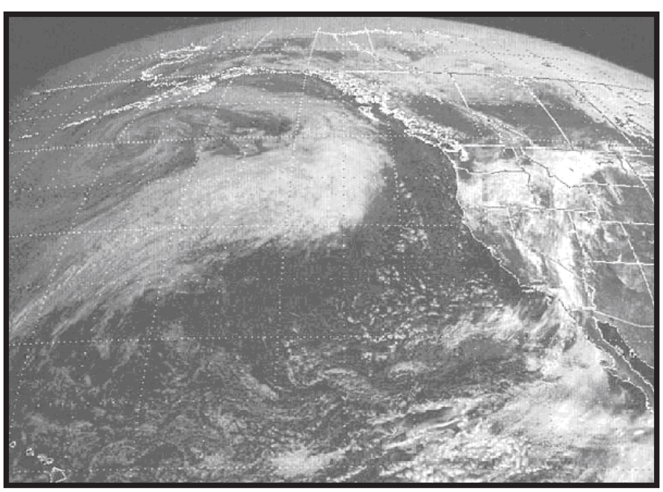

Figure 3-5. GOES-E VIS, 1715Z/26 April 1981.

Split-Flow Cyclogenesis

Many spring storm systems and their associated severe weather occurrences from the Rocky Mountains and Great Plains to the East Coast are associated with split-flow cyclogenesis that begins over the western CONUS. Eastern Pacific troughs entering the western CONUS during spring often diverge, following the splitting branches of the polar jet. The southern portion of the trough slows its eastward movement and digs southward along the western edge of the longwave trough. As the short wave nears the base of the longwave trough, it often initiates upper-level cyclogenesis. The northern short wave, on the other hand, progresses eastward along the northern branch of the polar jet. Figures 3-6 and 3-7 illustrate two examples. Further discussion on split-flow cyclogenesis is presented in *Winter Regimes*.

Forecasters may find it difficult at times to identify satellite deformation zones and vorticity comma cloud systems associated with these developing upper lows over the western CONUS. Mountain influences tend to dry out Pacific moisture, which will produce ill-defined deformation zone and vorticity comma cloud systems. Cloud elements that compose major comma cloud systems become better defined when the storm systems move out of the Rocky Mountains and encounter Gulf moisture advection.

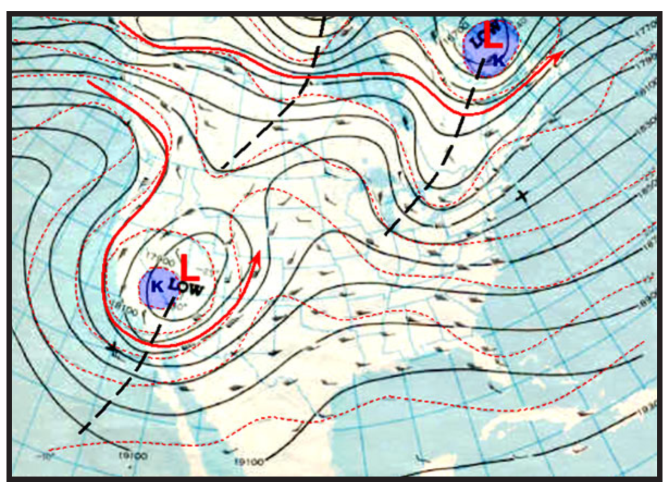

Figure 3-6. 500 mb, 1200Z/27 March 1981.

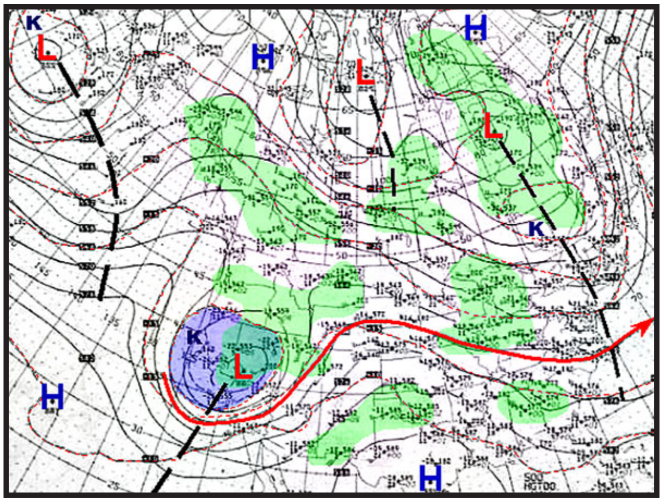

Figure 3-7. 500 mb, 1200Z/16 May 2001.

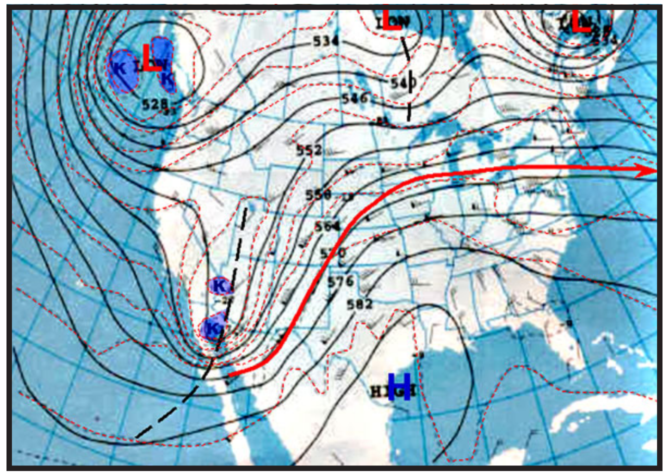

Figure 3-8. 500 mb 1200Z/6 April 2001. Intense short waves over the southwestern CONUS often spell trouble for the Great Plains within 24 hours.

March and April produce many rapidly-moving shortwave storm systems; accordingly, forecasters must be ready for rapid changes in the weather. During winter and mid-spring, some of these short waves decelerate and undergo cyclogenesis over the western CONUS. Weak height contour and thermal gradients; and cold air advection in conjunction with positive vorticity centers, height fall centers (HFCs) and jet stream maxima; are excellent indicators of imminent cyclogenesis (more detailed discussions are presented in *Winter Regimes*, pages 2-2 and 2-3). Figures 3-8 and 3-9 illustrate an early April event. In Figure 3-8, a Pacific short wave is over the southwestern CONUS. Note the weak height and thermal gradients from Arizona to Idaho. Tight height and thermal gradients over northern Mexico are associated with the jet stream. A low is likely to develop within the hatched area shown in Figure 3-8.

In the 500mb chart in Figure 3-9 (twenty-four hours later), a low appears over the northern Great Plains. An upper low developed within this trough twelve hours earlier, when the trough was over Arizona and New Mexico. The low then moved rapidly northeastward into the Great Plains.

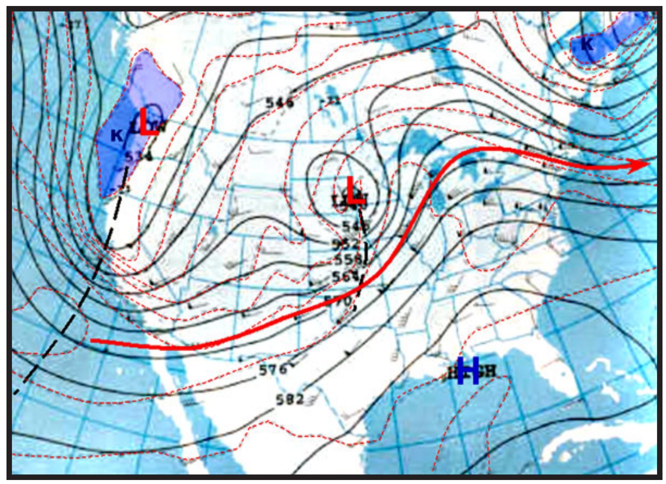

Figure 3-9. 500 mb 1200Z/7 April 2001. Low formed within the trough over the southwestern CONUS as shown in Figure 3-8.

North Pacific High

The North Pacific high continues to strengthen as the prevailing westerly flow shifts northward, replaced by upper-level subtropical ridging over the eastern Pacific Ocean. Figures 3-10a and 3-10b respectively depict late-spring surface analyses across the Pacific Ocean.

Frontal waves develop over the western Pacific and generally are in the occluded mature stage as they reach the West Coast of North America. The series of low pressure systems over the Pacific Ocean in the figures have shifted northward from their winter positions and have weaker circulations.

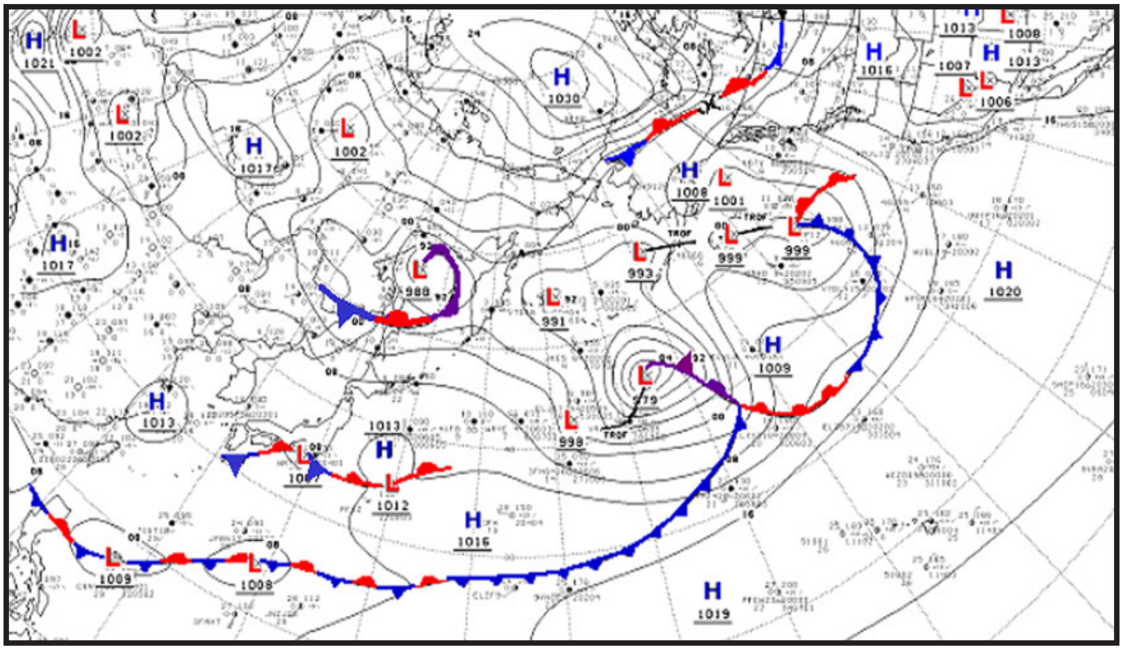

Figure 3-10a. Surface, 1800Z/26 May 2002.

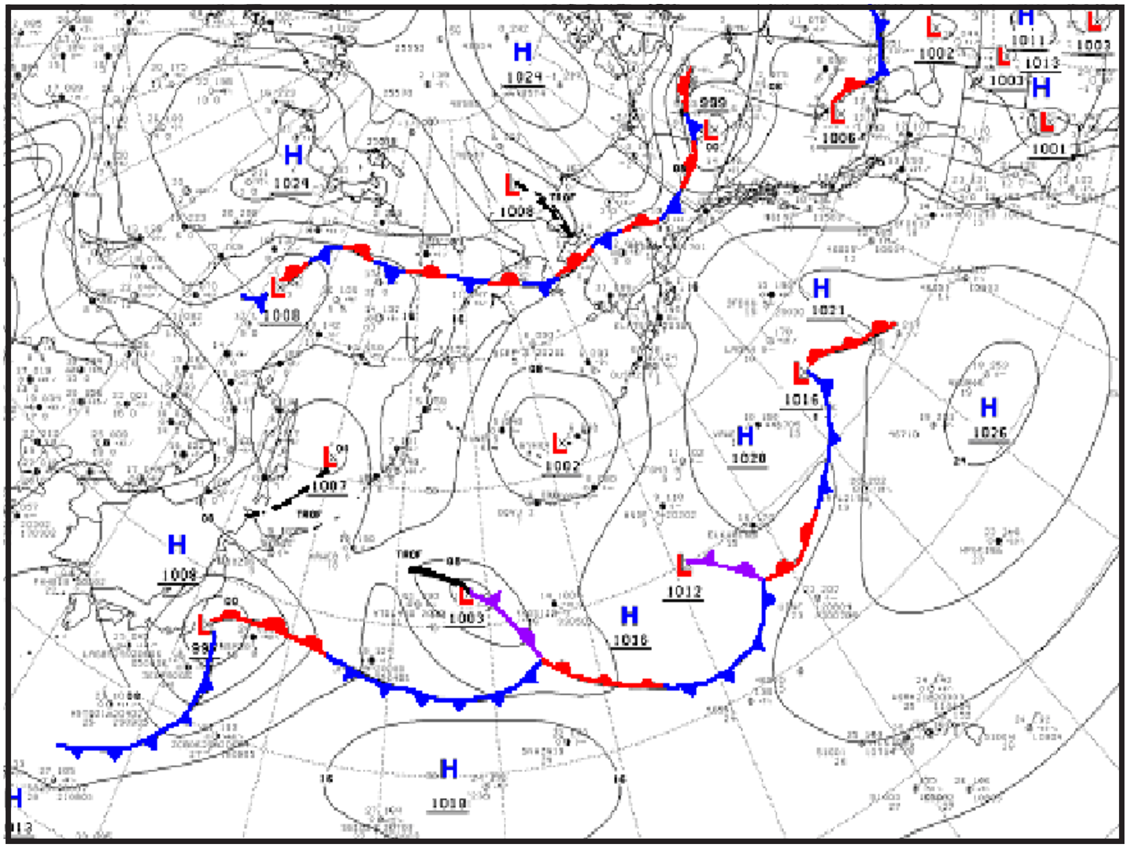

Figure 3-10b. Surface, 1200Z/18 June 2002.

Thermal Low/Coastal Stratus

A thermal low forming over Mexico during the spring builds northward, reaching the CONUS for the first time during March, and strengthening during April over southern California and Arizona. A typical warm season thermal trough (and associated low) is illustrated in Figures 3-11 and 3-12. The surface low becomes a closed feature in May.

The thermal low, in conjunction with the northward migration of the north Pacific high, produces a fetch of northerly winds down the coast. Coastal stratus increases significantly over southern California during March and continues through summer. Figure 3-13, related to Figure 3-12, depicts a typical cloud pattern along the California coast. Figure 3-14 also typifies this persistent ocean stratus regime.

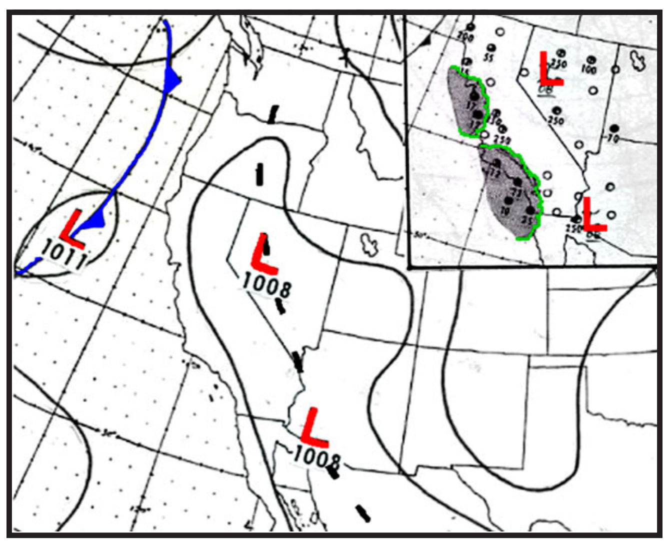

Figure 3-11. Surface, 1200Z/26 April 1980. The inset illustrates a cloud analysis of ocean stratus along the coastal areas.

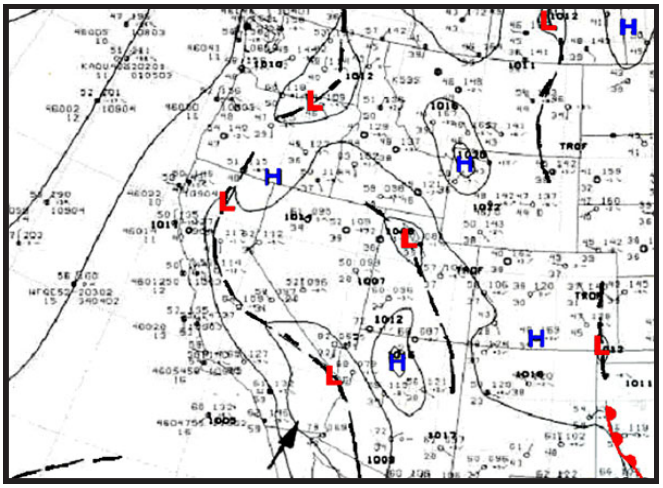

Figure 3-12. Surface, 1200Z/26 May 2001. A thermal trough, indicated by the dashed line (arrow), can be seen over Arizona and most of California.

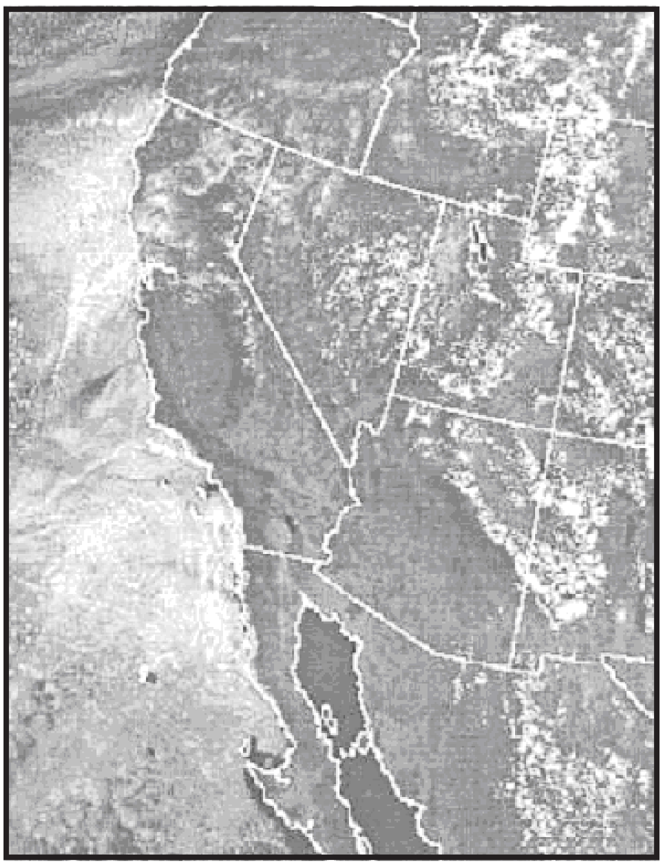

Figure 3-13. GOES-W VIS, 1930Z/25 May 2001. Photo taken approximately 16 hours prior to Figure 3-12. Ocean stratus hugs the coastline from Baja California to northern California.

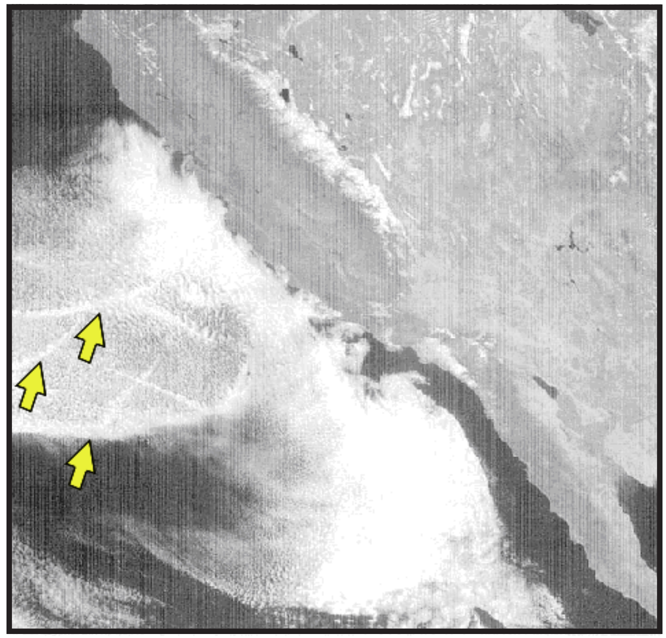

Figure 3-14. GOES-W VIS, 2100Z/13 April 1999. Ship trails (arrows) within stratus clouds. Snow is visible over the Sierra Nevada mountain range.

Other surface lows will appear over the Great Basin (Figure 3-15) and should not be mistaken for thermal lows. The Great Basin lows are transitory and are reflections of upper level cyclogenesis (Figure 3-16). In these events, weak or developing frontal systems may not be readily apparent on surface analyses.

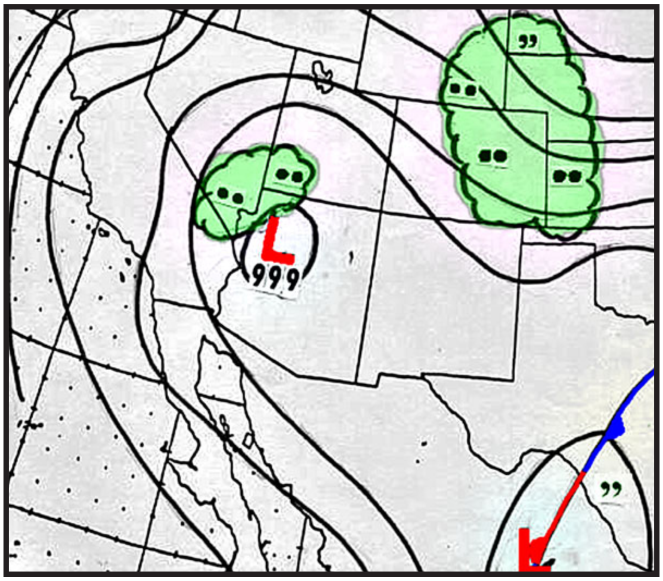

Figure 3-15. Surface, 1200Z/1 May 1978. Arizona low is associated with the upper low shown in Figure 3-16.

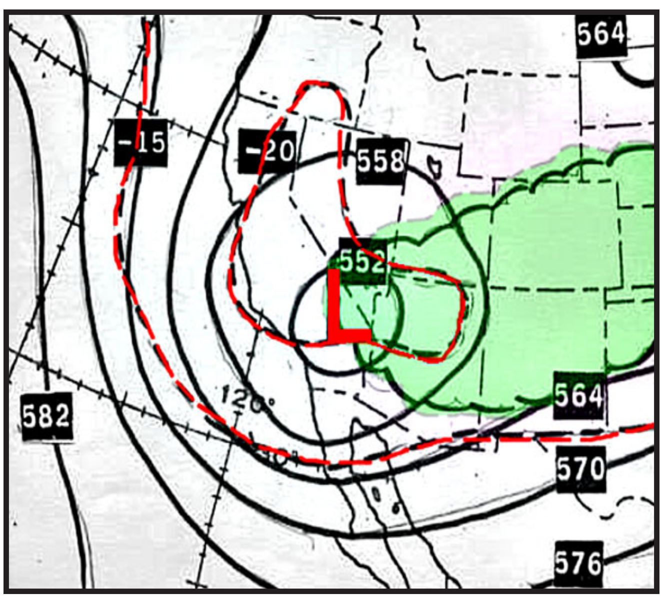

Figure 3-16. 500 mb, 1200Z/1 May 1978.

Fronts/Air Masses

Maritime Polar (mP) Fronts

An increase in maritime polar (mP) cold fronts, associated with Pacific short waves, will become the dominant frontal regime during spring across the western CONUS (Figure 3-17). As will be shown later, some of these mP cold fronts decelerate and undergo cyclogenesis in response to upper-level trough deepening.

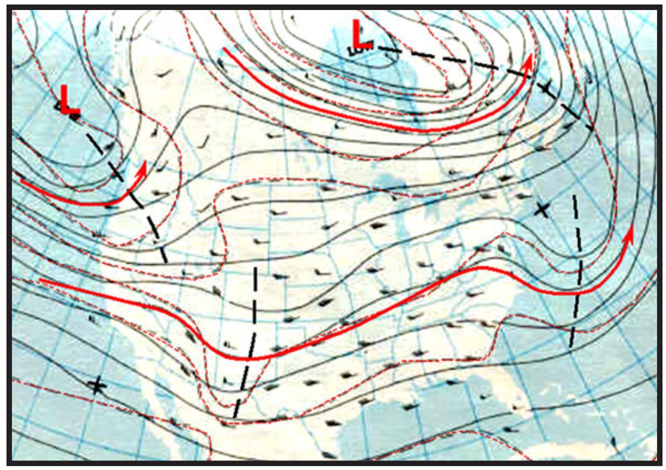

Figure 3-17. 500 mb, 1200Z/6 April 1980.

Continental Polar Fronts (cP)

Canadian air masses may continue to affect Montana, Idaho, Wyoming and Colorado through April (Figure 3-18 through 3-20).

By mid-spring, increasing solar insolation and termination of the Great Basin High regime (replaced by frequent cyclogenesis) ends the persistent valley fog events of late autumn and winter. Low clouds and fog may continue to occur in the Columbia Basin/Snake River Valley regions during early spring when these areas are still affected by continental polar air (Figures 3-18 through 3-20). Except for occasional occurrences, the regional stratus /fog problem is confined to the coastal areas for the next six months (Figures 3-13 and 3-14).

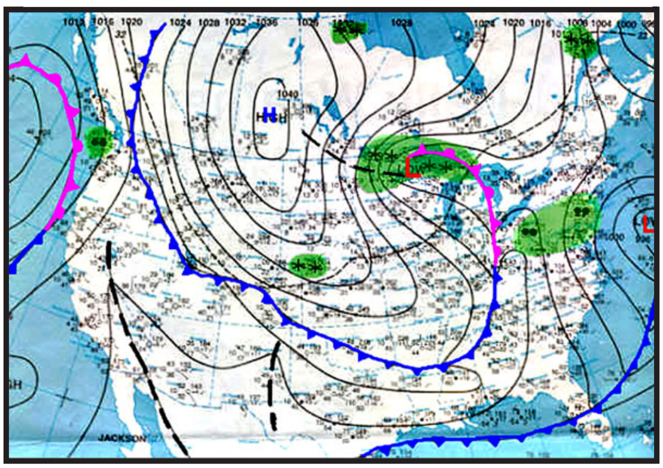

Figure 3-18. Surface, 1200Z/16 April 2001.

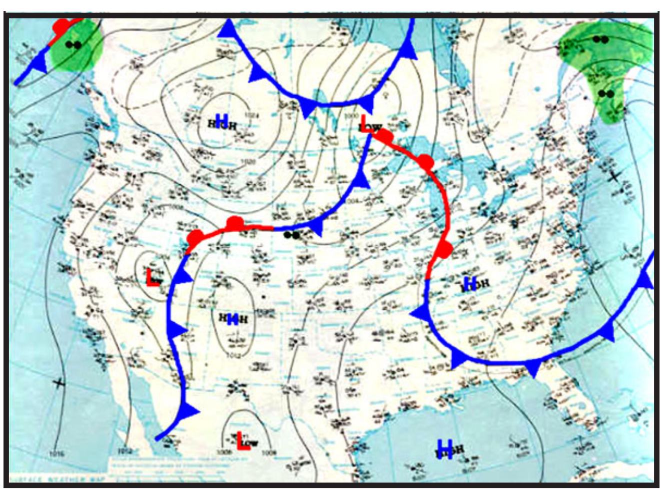

Figure 3-19. Surface, 1200Z/22 April 1980.

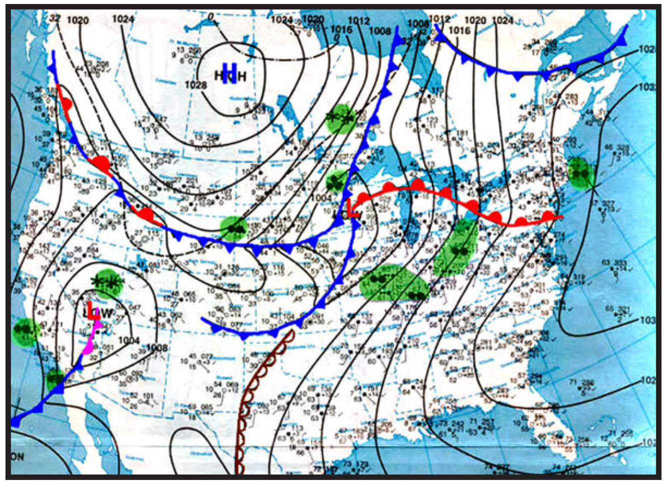

Figure 3-20. Surface, 1200Z/21 April 2001.

Great Basin High

The persistent Great Basin High Regime of winter generally ends in late March when longwave trough regimes terminate and are replaced by frequent Pacific shortwave systems. The Great Basin high may appear through May but its appearance is generally short-lived, and central pressures are lower than during winter events.

Quasi-Stationary Fronts

The quasi-stationary polar boundary that lies along the Canadian and northern CONUS Rocky Mountains during winter will persist into spring as Canadian air masses move southward into the northern Rockies and eastward across the northern Great Plains (Figures 3-21 and 3-22). The front separates the mountain-confined Great Basin High from transitory Canadian polar air masses. The front waves back and forth across central and eastern Montana and Wyoming when frontal lows either 1) develop over the area or 2) drop southward from Canada bringing in fresh outbreaks of Canadian polar air. Forecasters must monitor the strengths, trends and movements of the two anticyclonic systems to determine frontal locations and forecast weather conditions. Distinct weather events occur on either side of the frontal zone; cooler air occurs east of the front while warmer, dryer air prevails west of the front. In

Figure 3-21 (a late March event), the quasi-stationary front extends from the southern Canadian Rockies to Wyoming, where it transitions to a cold front. A ridge and several highs are shown over the Great Basin. Two months later (Figure 3-22), a late May event shows the quasi-stationary front and a weaker Great Basin high west of the front, as noted by the arrow. In both figures, this regime will likely produce strong daytime surface winds west of the front in Montana and Wyoming (an area known as the "Livingston Box" – to be discussed later in this chapter).

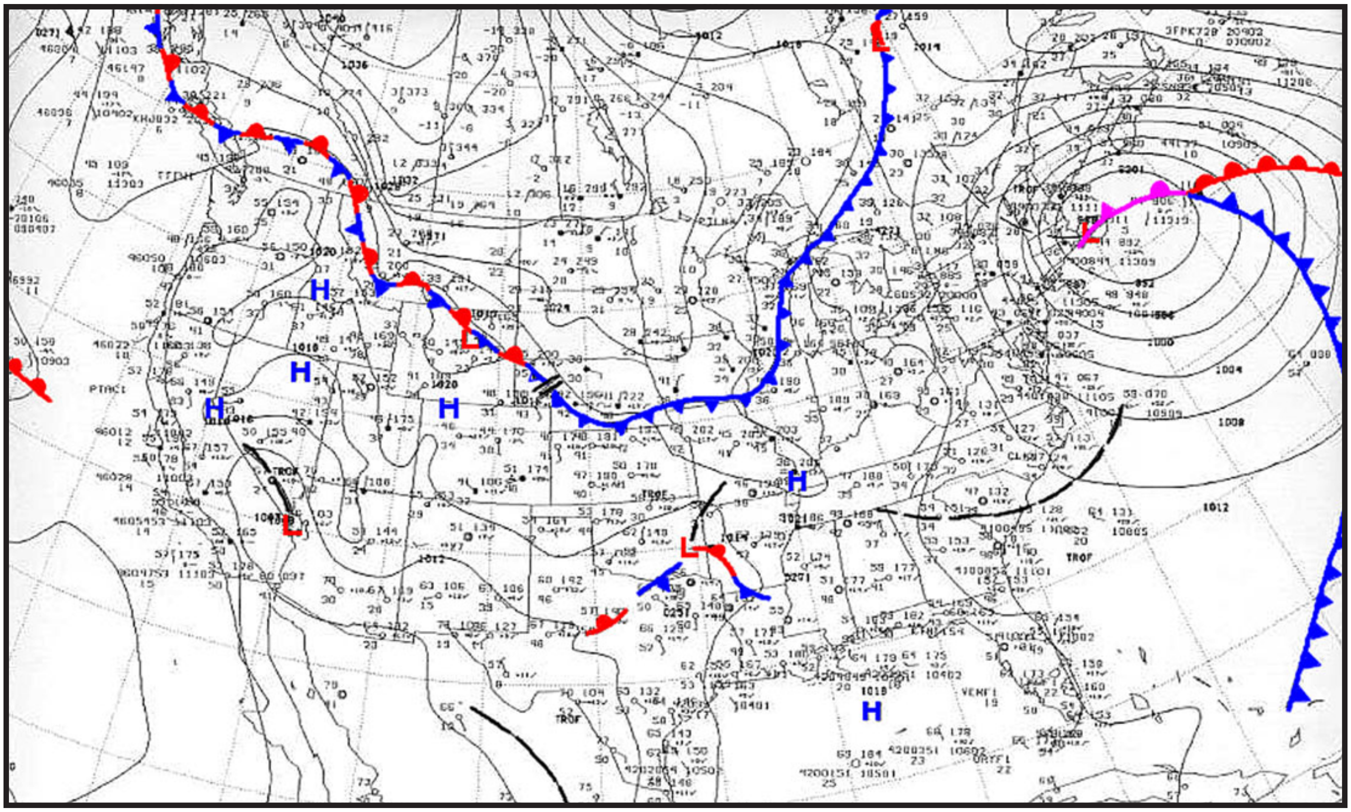

Figure 3-21. Surface, 0300Z/23 March 2001.

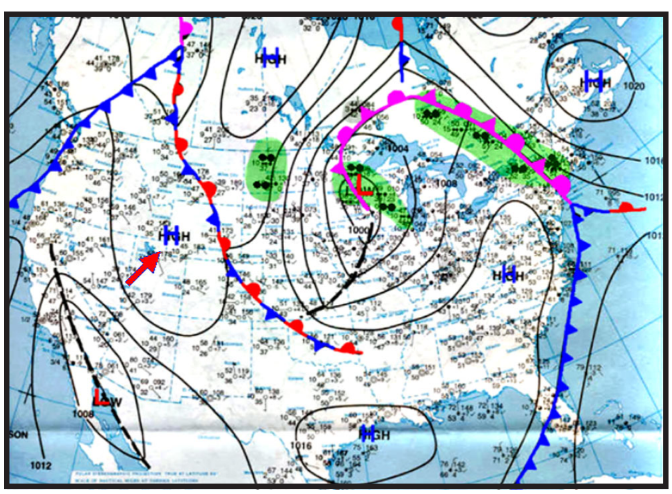

Figure 3-22. Surface, 1200Z/23 May 2001.

Surface Weather

When accompanied by snow, synoptic-scale storms may generate into early spring blizzards; local heavy snowfalls are likely. A threat of winter snowstorms over Montana, particularly eastern Montana and the northern portion of the intermountain region, continue through April. Intense storm systems moving out of the Rocky Mountains from Colorado or Wyoming lift northward toward the upper Great Plains and produce heavy snowfalls over the eastern and central areas of Montana (Fig. 3-23; further discussion in Figs. 3-40 through 3-45).

The most frequent weather event in March over the western CONUS is the windstorm. The notorious wind events of winter continue into early spring; these regimes will be discussed later in *Notorious Wind Regimes*.

Freezing precipitation events may occur over Montana and northern Idaho at the onset of spring when cP air masses still prevail, but they usually terminate by the end of March (see *Winter Regimes* for more detail).

Precipitation continues its seasonal decline along the West Coast throughout the period. However, west of the Cascades and in northwestern California, precipitation begins to *increase* throughout the period as more Pacific frontal systems track across the region (Figure 3-24). During May, thunderstorms increase substantially over Nevada, Utah, Idaho and Montana with smaller increases in Washington, Oregon, California and Arizona.

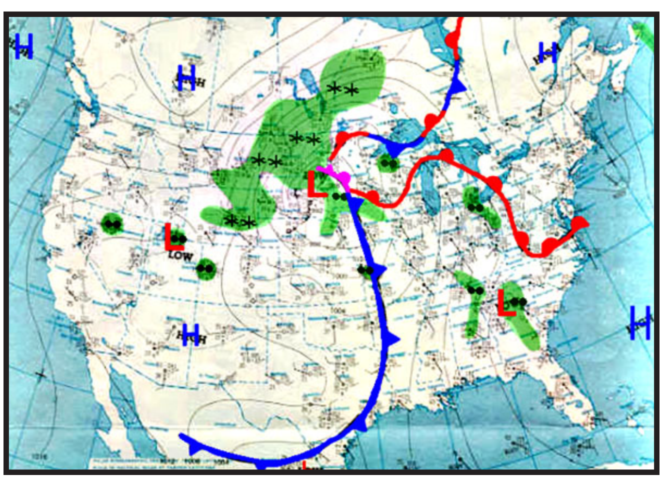

Figure 3-23. Surface, 1200Z/27 April 1984. Snow is occurring over eastern Montana and Wyoming.

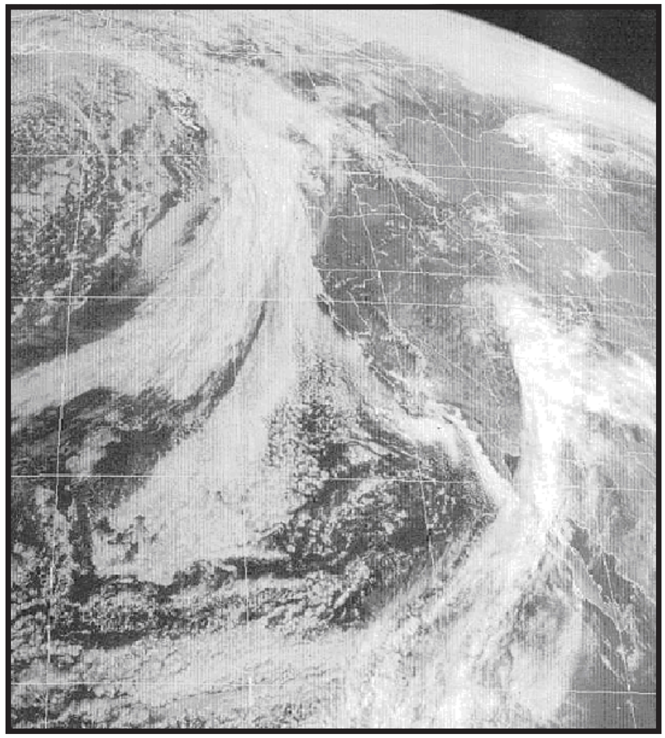

Figure 3-24. GOES W VIS, 1615Z/21 April 2000.

Storm Tracks

Great Basin Frontal Cyclogenesis

Many Pacific frontal systems move across the CONUS during the spring season (Figures 3-17 and 3-25). Over the western CONUS some of these frontal systems experience cyclogenesis (Figure 3-26), especially in the Great Basin region (Figure 3-27). They may become significant storm systems over the Rocky Mountains and eastward within 24 hours.

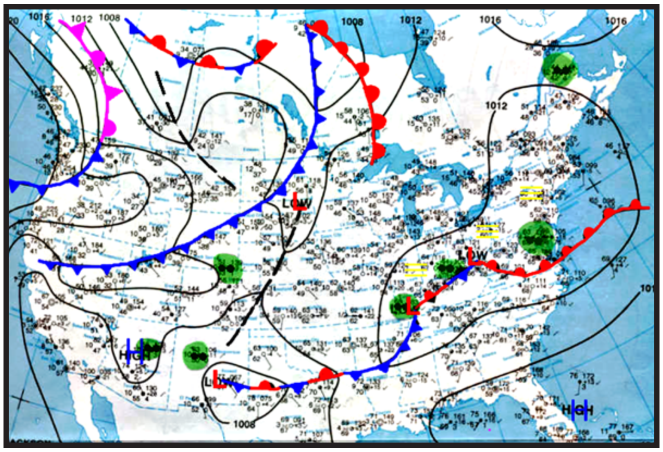

Figure 3-25. Surface, 1200Z/19 May 2001. Succession of mP cold fronts over the CONUS.

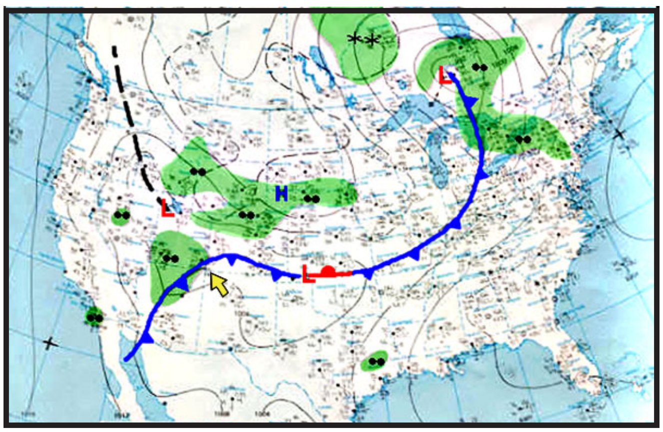

Figure 3-26. Surface, 1200Z/11 May 1980. Frontal waving (arrow) suggests cyclogenesis over the Great Basin region.

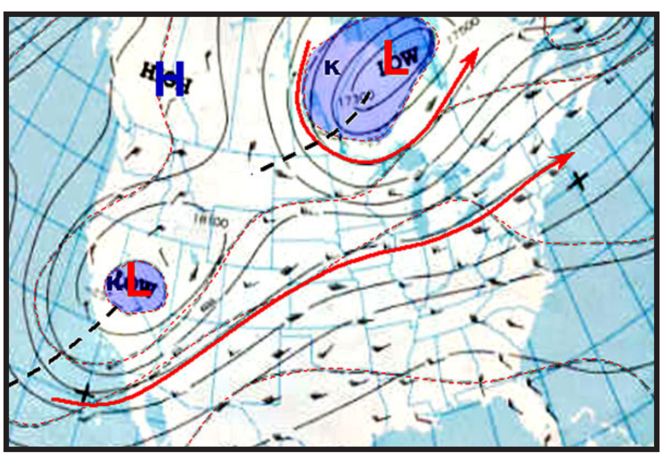

Figure 3-27. 500 mb, 1200Z/11 May 1980. Related to Figure 3-26. Typical upper support for frontal cyclogenesis over the Great Basin region.

Figures 3-26 and 3-27 illustrate a typical setup for frontal cyclogenesis over the western CONUS, especially over the Great Basin region. Pacific cold fronts decelerate and often become oriented east-west, after which time a frontal wave develops (Figure 3-26) due to shortwave deepening and upper-level cyclogenesis (Figure 3-27). Another example is shown in Figures 3-28 and 3-29.

During March and April, it is not uncommon for a succession of short waves to travel rapidly across the CONUS (Figures 3-28 and 3-29). Figure 3-28 depicts two short waves over the central CONUS. The short wave shown over the Great Plains in Figure 3-28 was located over Arizona 24-hours earlier. Twelve hours later, a low developed within this short wave over the central Rocky Mountains, then the system lifted to the northeast. Also in Figure 3-28, a second short wave has entered the West Coast with an associated closed low to its north. The low dropped southward and was located over the southern California/Arizona region within 48 hours.

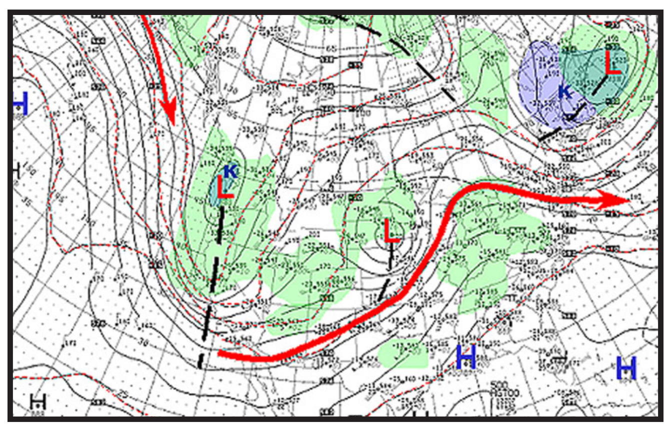

Figure 3-28. 500 mb, 1200Z/7 April 2001.

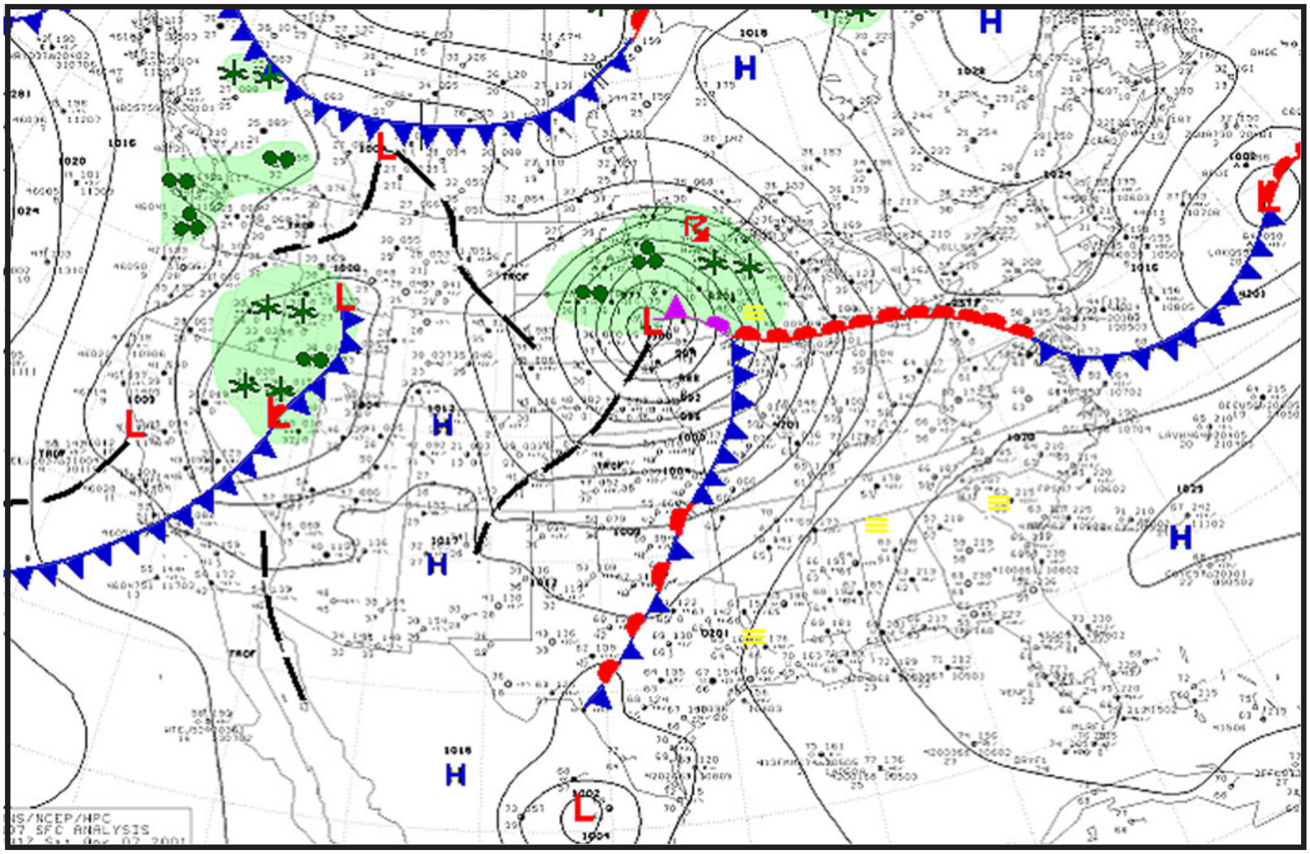

Figure 3-29. Surface, 1200Z/7 April 2001.

Figure 3-29 depicts the surface conditions associated with the two aforementioned short waves. A major storm system is shown over the Great Plains. The Pacific cold front shown over the western CONUS moved southeastward into the southern Rockies. A frontal wave intensified over New Mexico as the upper low approached from Arizona. A major storm evolved over the central Rocky Mountains within 12 hours. Figures 3-30 and 3-31 illustrate another example.

Frontal waving over the Great Basin region during March and April produces a variety of weather conditions over the western CONUS (and later over the central CONUS).

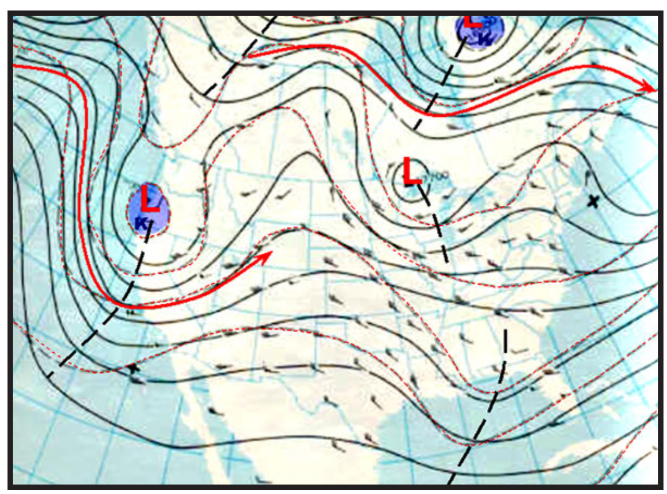

Figure 3-30. 500 mb, 1200Z/26 March 1981. Short wave entering the West Coast. Upper low appears along the Oregon coast (compare to Figure 3-28).

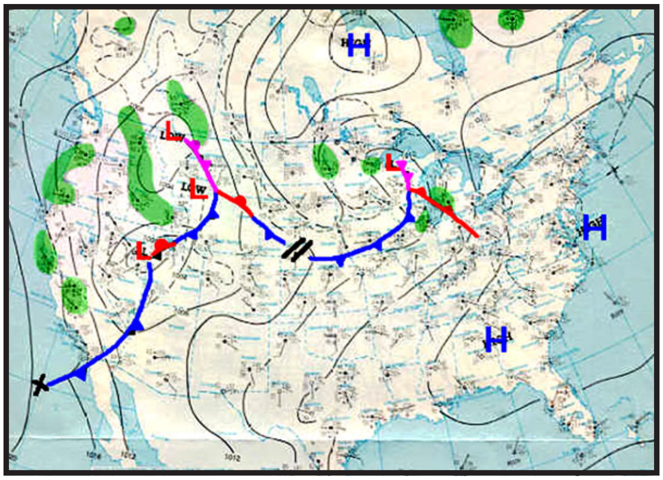

Figure 3-31. Surface, 1200Z/26 March 1981. Frontal waving over the Great Basin region has begun. Upper low shown off the Oregon coast in Figure 3-30 will likely dig southeastward and eventually stack with the frontal low over Utah.

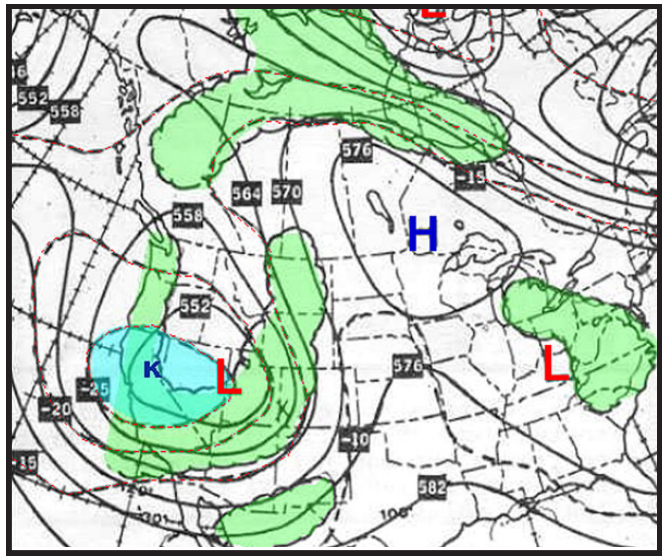

Figure 3-32. 500 mb, 0000Z/25 May 1980. A stationary ridge lies across the central CONUS. The blocking action will lift the Great Basin storm system northward.

Blocking Ridges –Northward Moving Storms

During May and continuing into early summer, storm systems developing from the Great Basin to the central Rockies occasionally move northward into the northern Rockies. Significant precipitation may occur. Cutoff lows and blocking ridges (see Chapter 2) initiate this regime. Figures 3-32 through 3-35 illustrate an example. Note the northerly movements of the upper lows in Figures 3-32 and 3-34; the surface low over Colorado in Figure 3-33 moved northwestward into Montana 12 hours later (Figure 3-35).

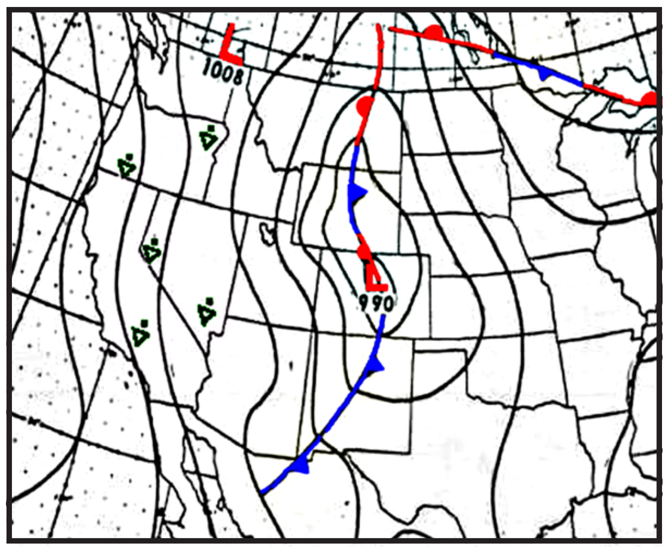

Figure 3-33. Surface, 0000Z/25 May 1980. Colorado low will move northward along stationary front.

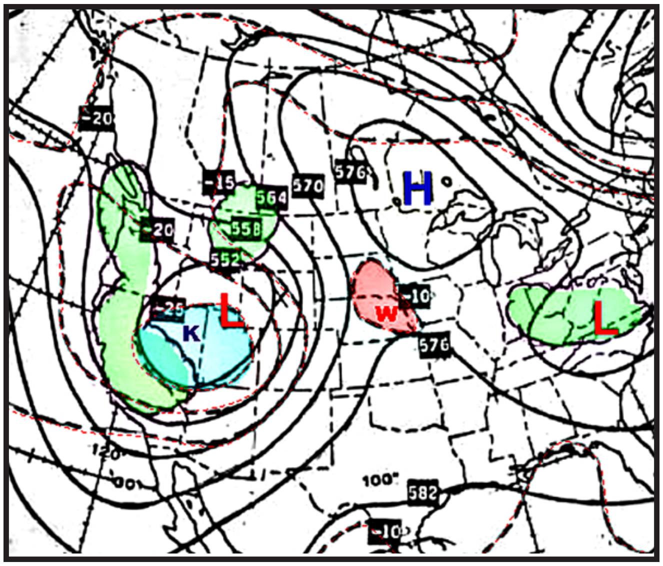

Figure 3-34. 500 mb, 1200Z/25 May 1980. Low continues to move northward.

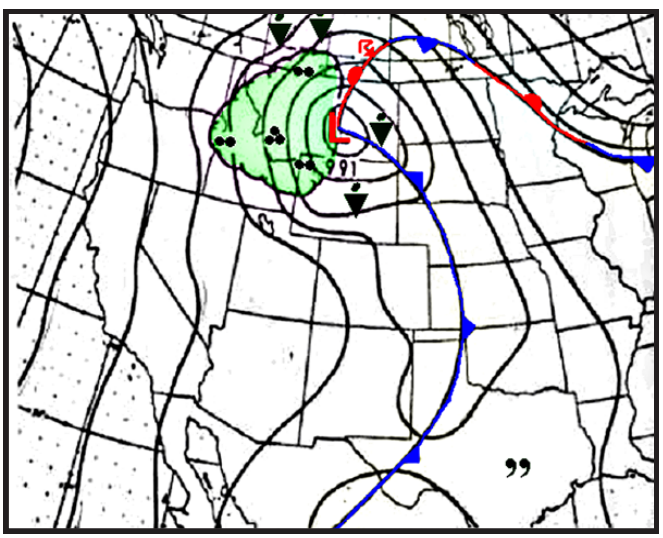

Figure 3-35. Surface, 1200Z/25 May 1980. Surface low associated with the upper low appears over Montana.

Another example of the blocking regime that occurs in spring over the western CONUS is shown in Figures 3-36 through 3-39.

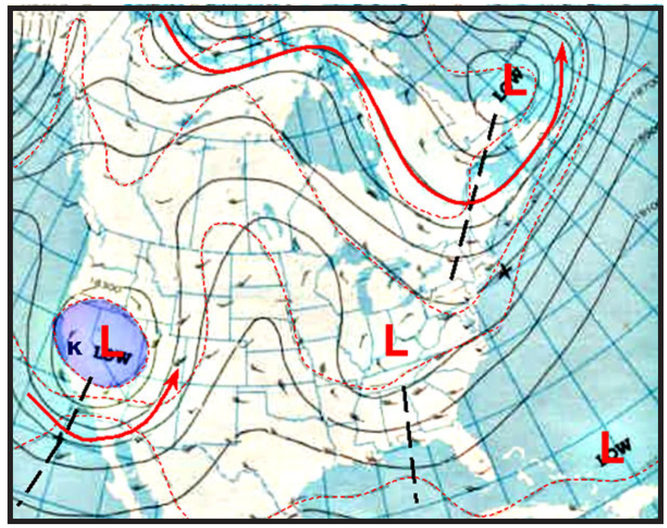

Figure 3-36. 500 mb, 1200Z/20 May 1981. Strong upper level ridging lies across the central Plains.

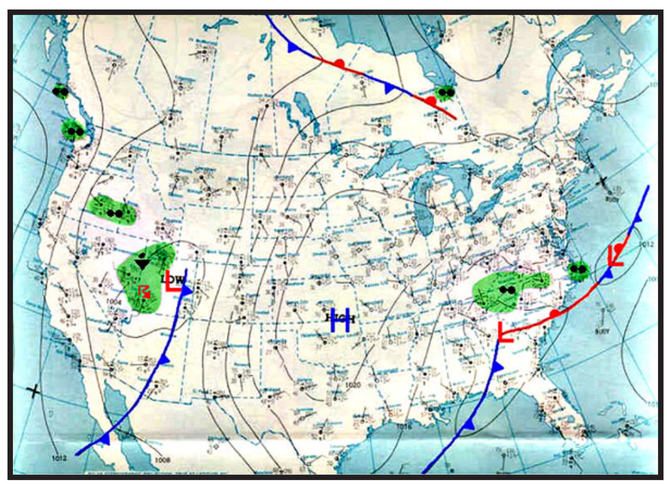

Figure 3-37. Surface, 1200Z/20 May 1981. Associated surface low (ref Figure 3-36) over the Great Basin area.

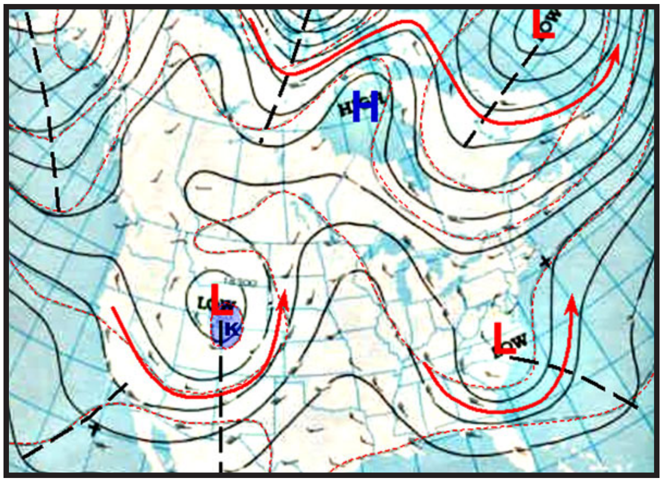

Figure 3-38. 500 mb, 1200Z/21 May 1981. Upper low over Rockies lifting northeastward as strong ridging continues over the Great Plains.

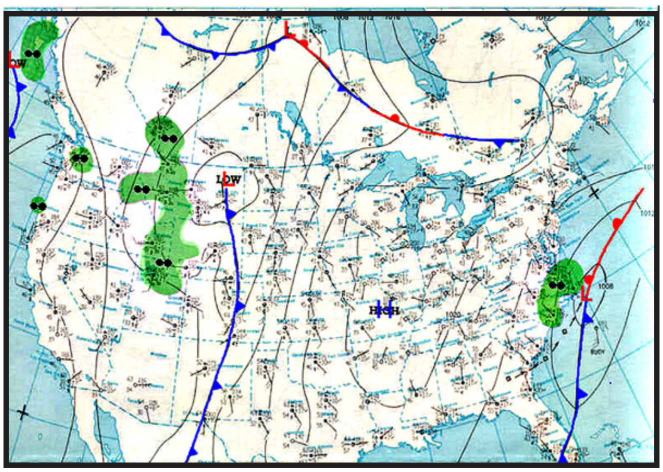

Figure 3-39. Surface, 1200Z/21 May 1981. The low over Great Basin has lifted northeastward into eastern Montana.

Rocky Mountain Cyclogenesis

During March and April, the region east of the Rocky Mountains, from northeastern Colorado/eastern Wyoming to eastern Montana, will experience several heavy snow events--including full-fledged blizzards--when cyclogenesis occurs to the south over eastern Colorado (Colorado Low regime) and/or the western Great Plains. Heavy snow and strong winds affect these areas when deepening lows lift northward toward the northern Great Plains. Figure 3-40 outlines the areas within the western CONUS that are affected by blizzards.

Figures 3-41 through 3-45 illustrates an event that blanketed eastern Colorado to eastern Montana with heavy snowfall. In Figure 3-41, a deep short wave is noted over the western CONUS. The yellow box shown over Nevada and Utah would be a favorable area for cyclogenesis.

Figures 3-43 through 3-44 show events that occurred 24 hours later. A low formed within the upper trough and has moved southeastward into Colorado as depicted in Figure 3-43. Also, in Figure 3-43, a strong ridge is in place over the eastern CONUS; the Colorado low will likely lift northward due to the blocking action of the ridge.

Finally, in Figures 3-45 and 3-46, the Colorado low has moved northeastward into South Dakota. The CONUS ridge has shifted a little to the east and has forced the Great Plains low northward. See Chapter Four for further discussion of the Colorado Low regime.

Notorious Wind Boxes – Western CONUS

Forecasting strong non-convective surface winds over the western CONUS is often a challenge. Coastal and mountain areas have a strong influence on the strength of surface winds. Other factors include Pacific upper troughs, that often undergo changes across the mountains from the Cascades/Sierras to the Rockies due to terrain effects. Deepening troughs result in surface cyclogenesis in mountain areas and may produce strong orographic and gradient winds.

Strong (> 35 kts) winds advecting cold air can occur anywhere over the western CONUS. There are, however, several infamous high wind areas (“boxes”). Figure 3-47 shows these *Notorious Wind Boxes*. The frequency of occurrence of high winds diminishes by mid-spring as the polar jet moves northward. The *Livingston* and *Dusty* Boxes are generally the more active boxes over the western CONUS through April.

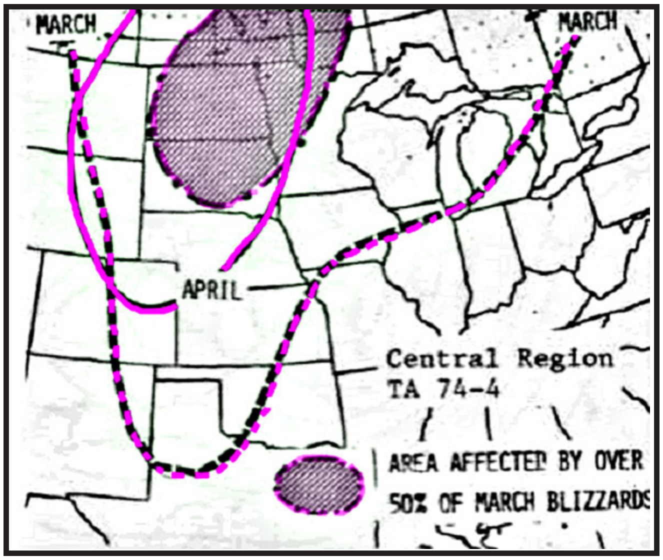

Figure 3-40. Areas Affected by Blizzards During March and April.

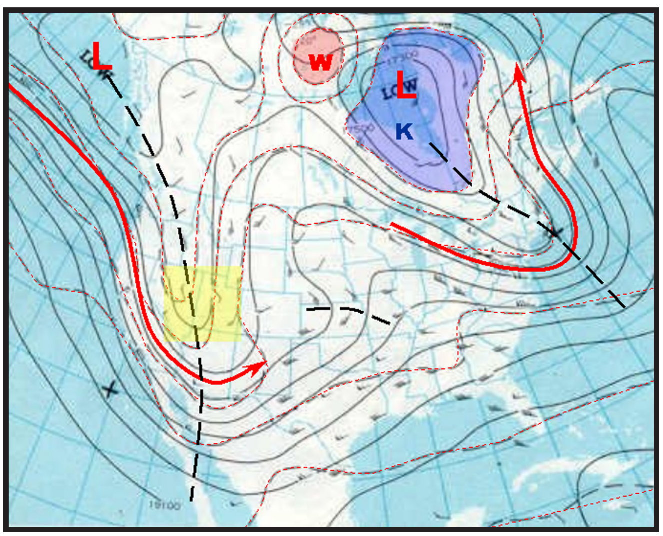

Figure 3-41. 500 mb, 1200Z/10 April 1979. Digging trough shown over the western CONUS. Yellow box represents an area of probable cyclogenesis. Minor short wave appears over Kansas and Nebraska.

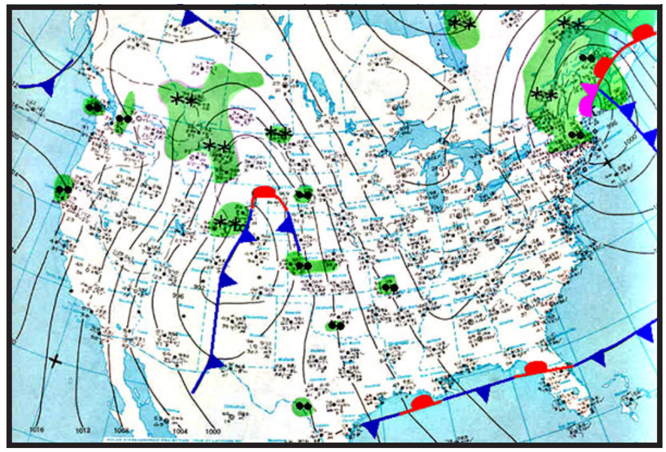

Figure 3-42. Surface, 1200Z/10 April 1979. A frontal low has developed within a large cyclonic circulation. Gulf moisture has advected northward within the tight east-west pressure gradient over the Great Plains.

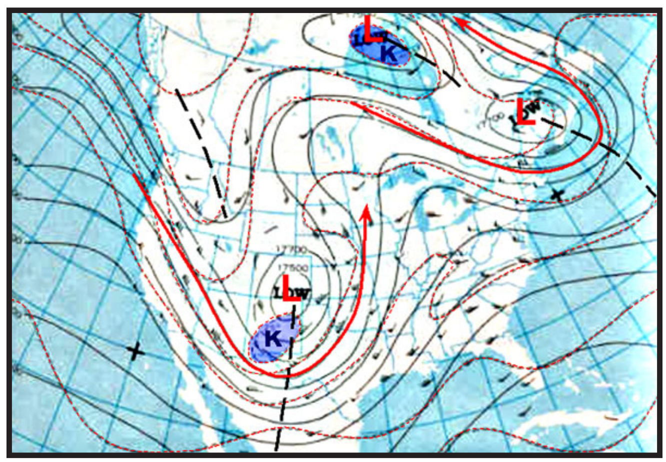

Figure 3-43. 500 mb, 1200Z/11 April 1979. Fully-developed low over Colorado is poised to move toward the northern Great Plains.

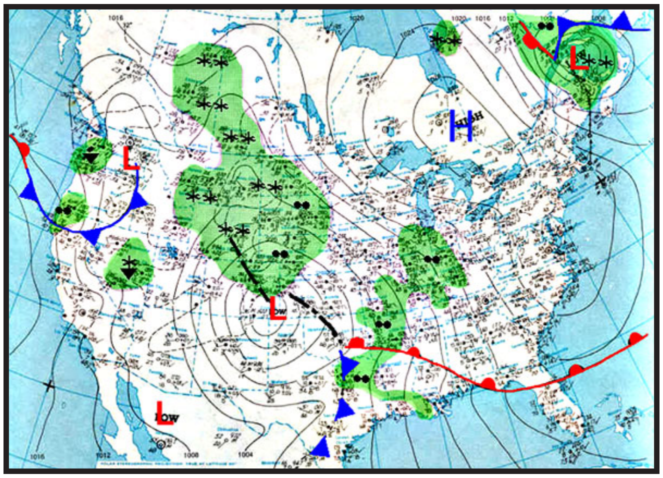

Figure 3-44. Surface, 1200Z/11 April 1979. Low has deepened over Colorado and stacks with the upper low. Large-scale cyclonic circulation. Pre-frontal rains have developed over the lower Mississippi Valley and northward. Extensive snow falling over the central and northern Rockies and the northern Great Plains.

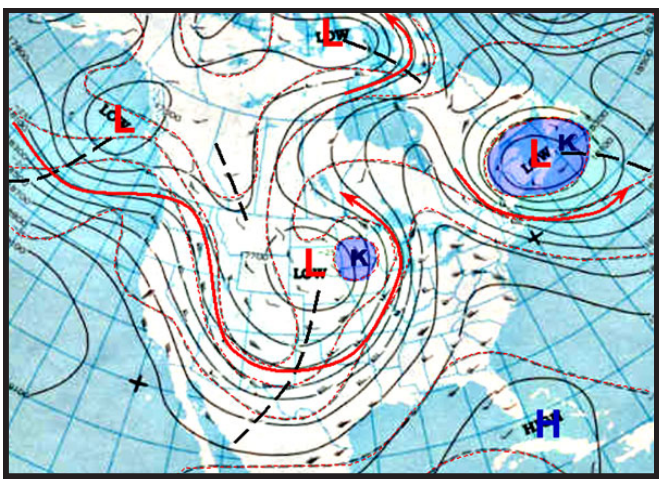

Figure 3-45. 500 mb, 1200Z/12 April 1979.

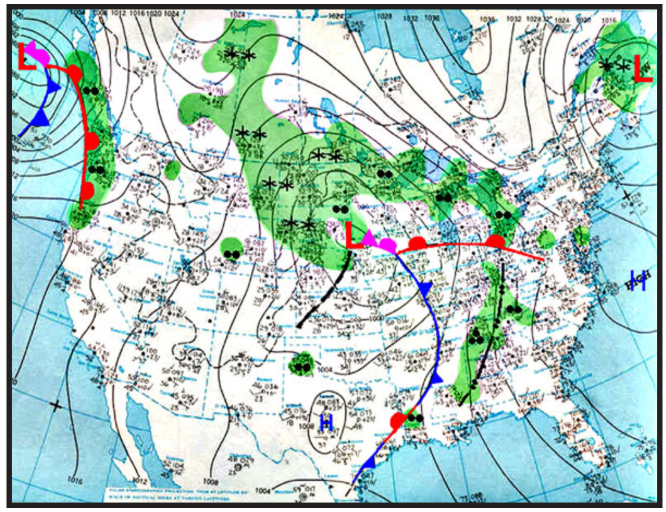

Figure 3-46. Surface, 1200Z/12 April 1979. Snow continues over the northern Great Plains and eastern Montana and Wyoming.

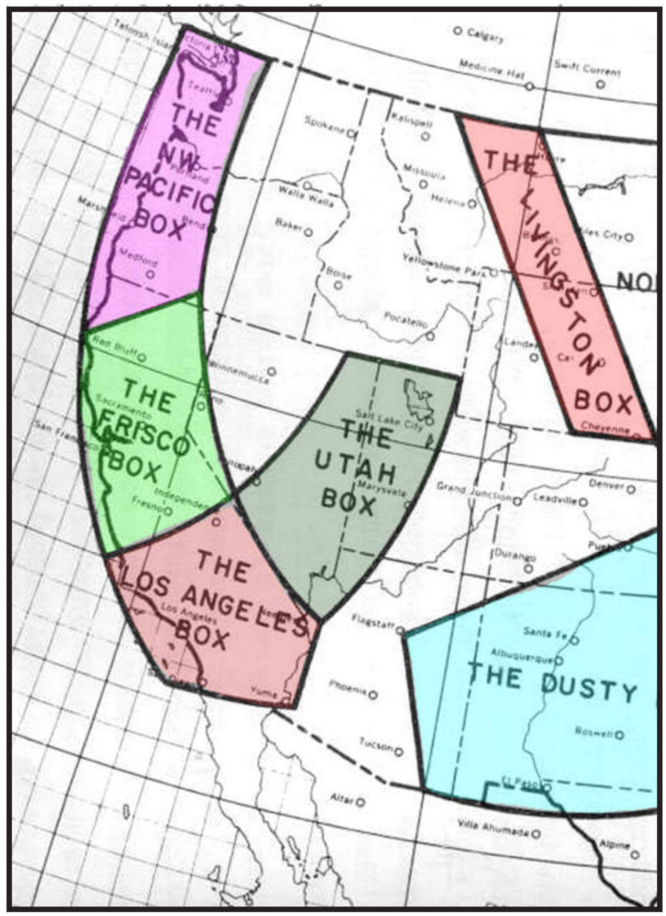

Figure 3-47. Notorious Wind Boxes – Western CONUS. Map depicts areas frequently affected by strong non-convective surface winds (>35 knots) across the CONUS.

Northwest Pacific Box

The *Northwest Pacific Box* is associated with major storm tracks (Figure 3-48). When large-scale storm systems move through the eastern Pacific between 40º and 50ºN latitude, strong winds within the box begin shortly before the system's arrival, and may continue for 24 hours thereafter. Figure 3-49 depicts the coastal reporting stations affected by these winds. Figure 3-50 shows an example of the Northwest Pacific wind regime during mid-March; the inset depicts the associated 500-mb short wave.

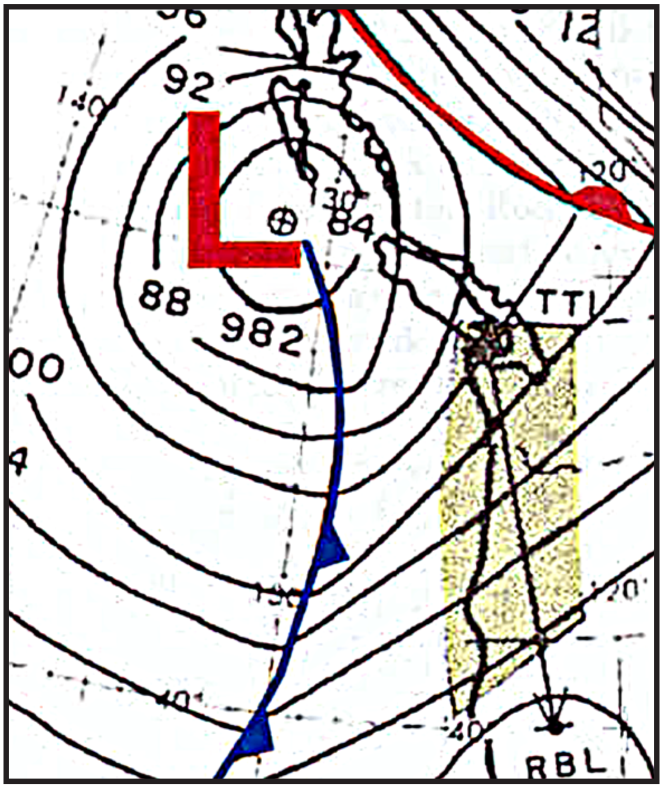

Figure 3-48. Northwest Pacific Box

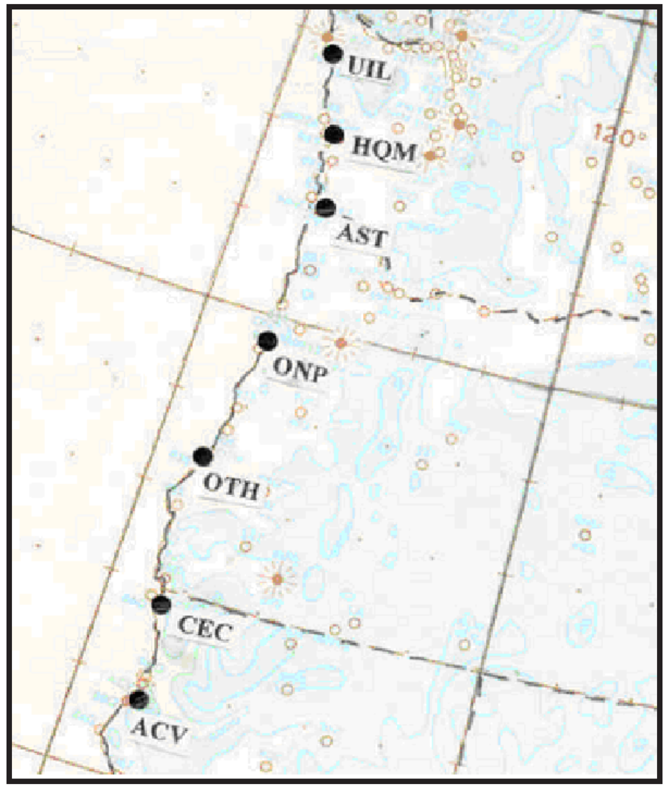

Figure 3-49. Stations in the Northwest Pacific Box

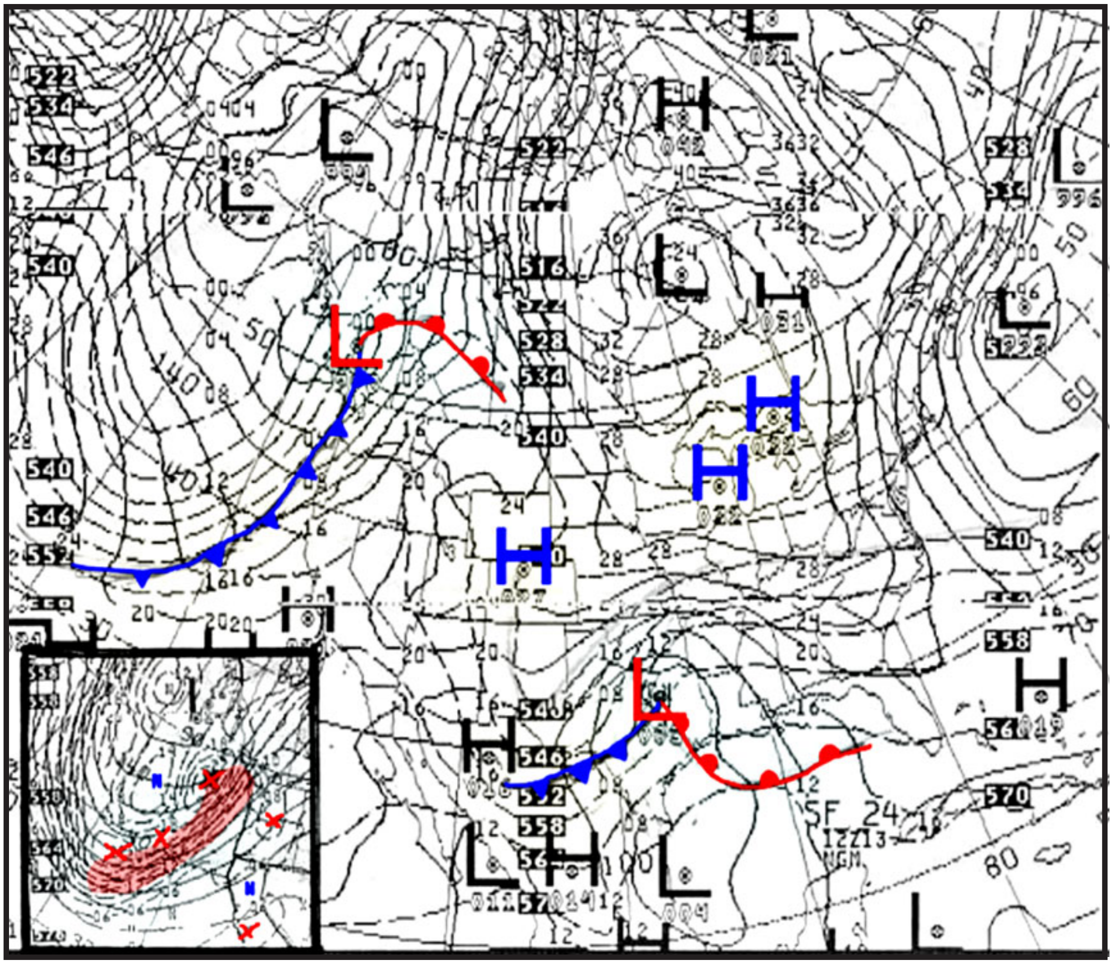

Figure 3-50. 24-HR MSL PRES/1000-500MB THCKNS, 1200Z/13 March 1999.
INSET: 500 mb Heights/Vorticity, 1200Z/13 March 1999

Frisco Box

The *Frisco Box* wind regime occurs when low-pressure systems enter the West Coast over California. The synoptic pattern shown in Figure 3-51 activates a south-to-southwesterly wind event over central and northern California. Figures 3-52 and 3-53 respectively show the low-level and mid-level maximum winds. This regime generally ends by early April.

Compare the visible satellite image shown in Figure 3-54 to the surface chart in Figure 3-51.

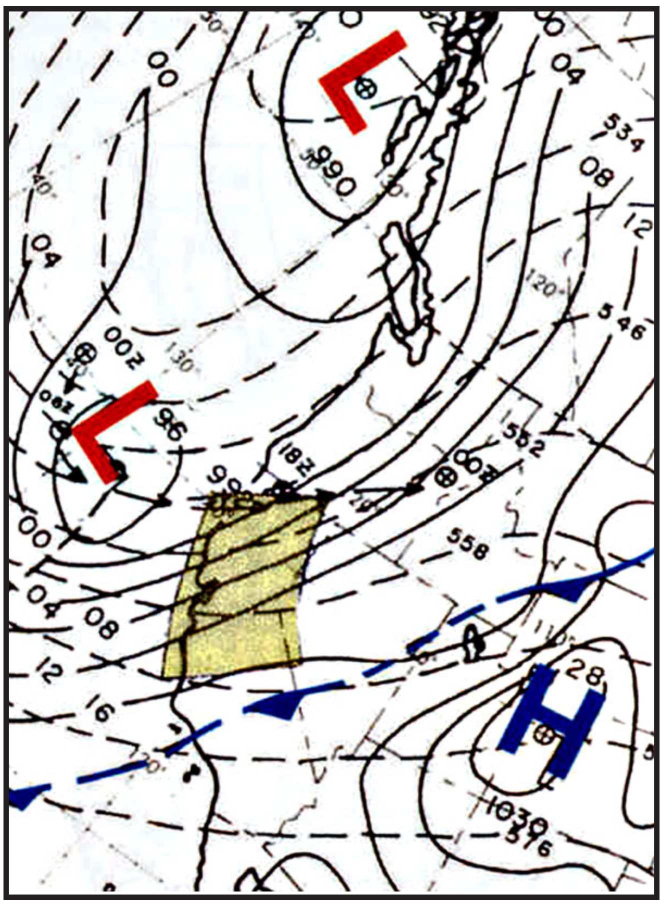

Figure 3-51. The Frisco Box. The tight pressure gradient ahead of the approaching low will produce winds in excess of 35 knots along the coast. Great Basin High appears over Colorado.

Figure 3-52. Frisco Box Low-Level Maximum Winds. Strong winds usually begin when the storm center is within 200 miles of the coast.

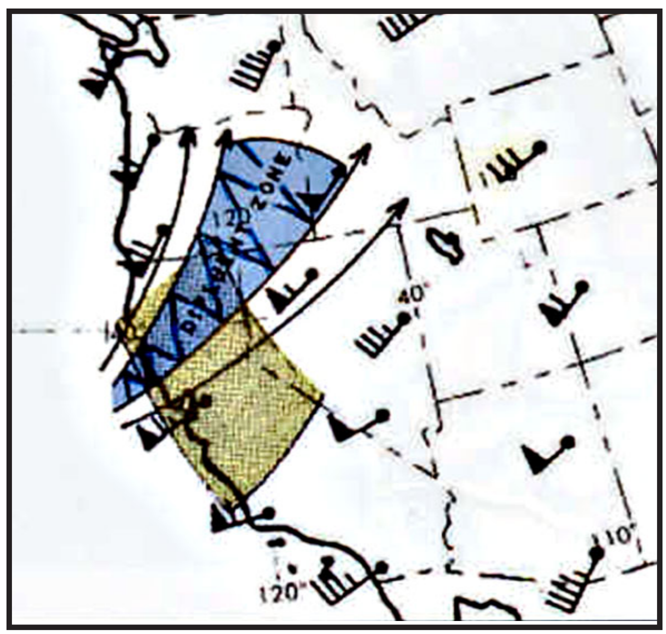

Figure 3-53. Frisco Box Mid-Level Maximum Winds. Southwest difluent wind flow within the middle levels enhances strong surface winds.

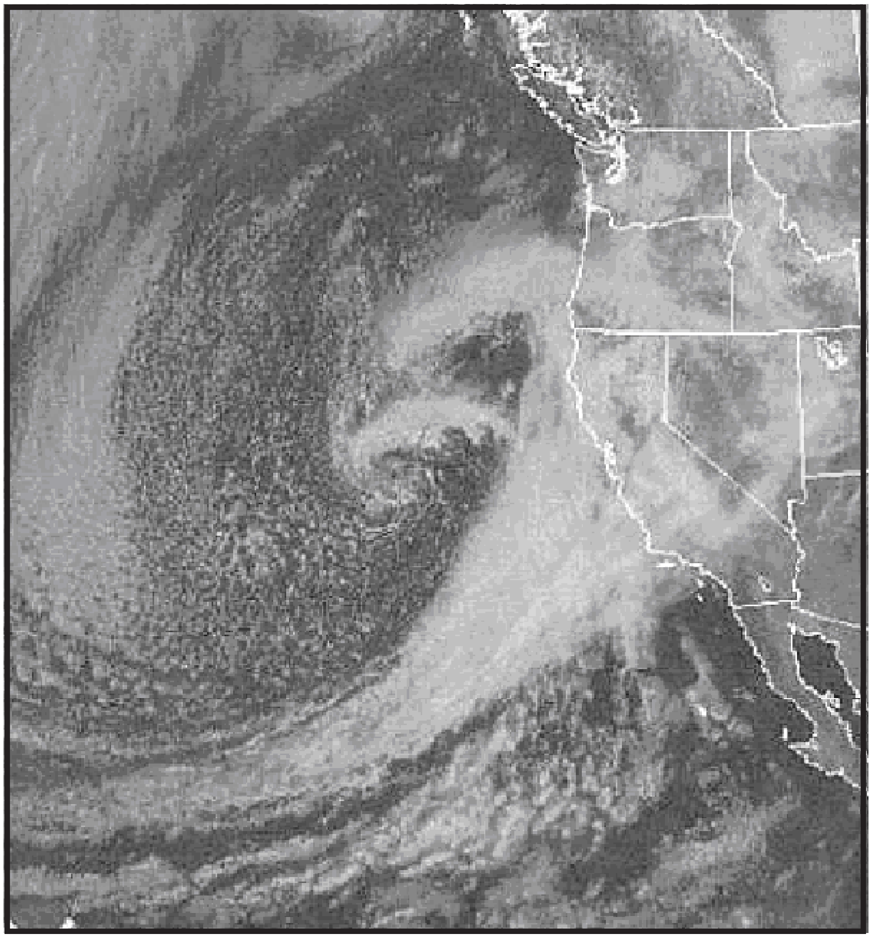

Figure 3-54. GOES W VIS, 1730Z/16 April 2001

Los Angeles Box – Example 1

Two synoptic patterns that produce strong northwesterly to northerly surface winds are shown in Figures 3-55 and 3-56. In Figure 3-55, strong northwesterly winds associated with a digging upper trough follow a cold FROPA. Tight surface pressure gradients are not always evident over California, and that may mislead forecasters into thinking that strong winds will not occur. Figures 3-55 and 3-56 show north-to-northwest wind flow that extends into the upper troposphere. Figure 3-57, on the other hand, illustrates a mid-level synoptic pattern favorable for north and northeasterly *Santa Ana* winds. Figures 3-58 and 3-59 illustrate another example.

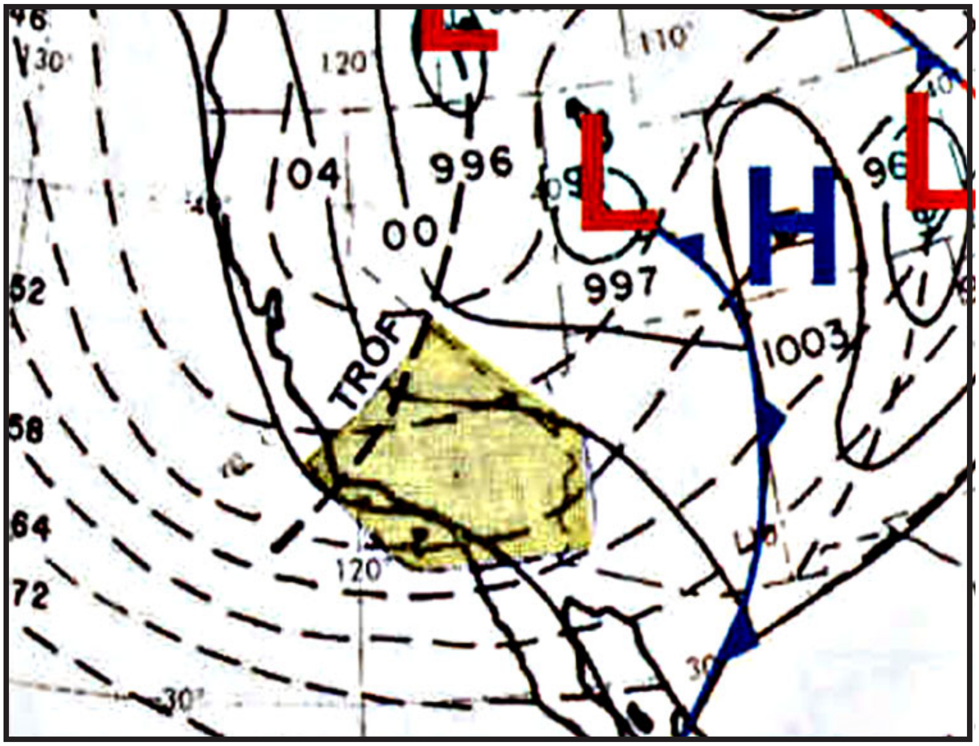

Figure 3-55. Los Angeles Box Surface, Example.

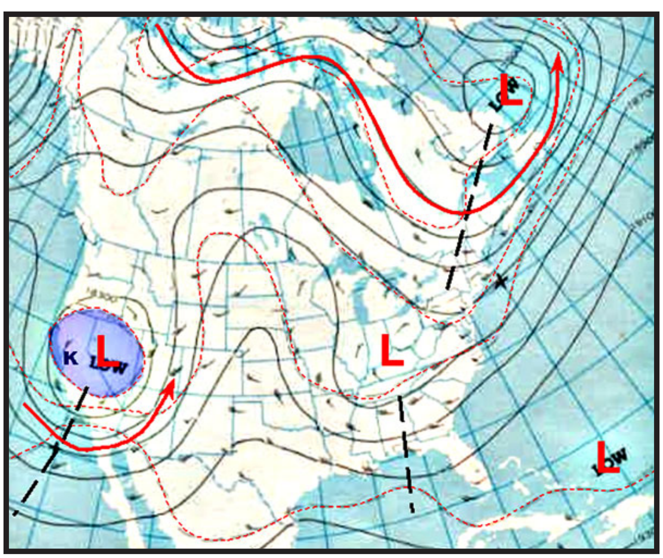

Figure 3-56. Los Angeles Box 500 mb, Example

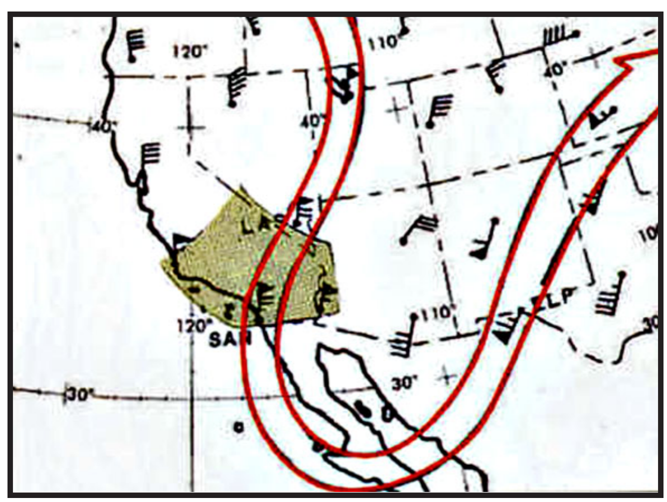

Figure 3-57. Los Angeles Box Mid-Level Maximum Winds

During spring upper lows move across the southwestern CONUS frequently. The intensity of mid- and high-level jet streams associated with these upper lows are not as strong as during winter events; however, strong surface winds are likely over southern California and Arizona, especially during the daylight hours.

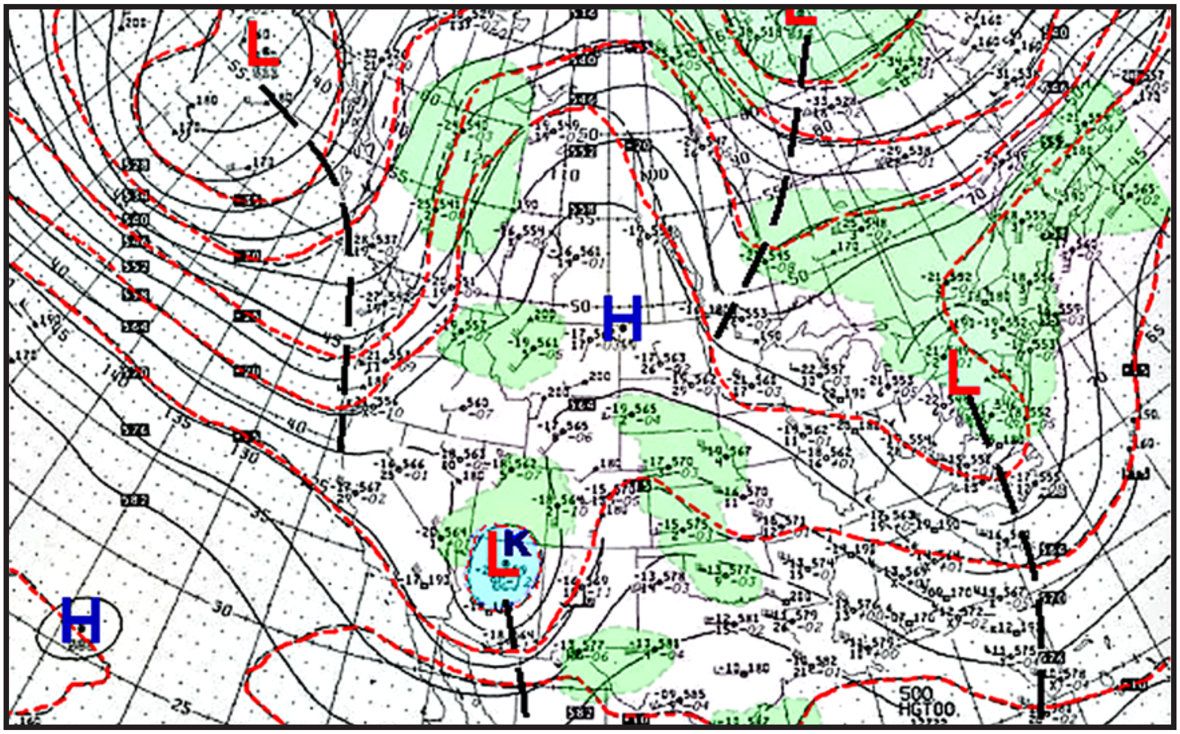

Figure 3-58. 500 mb, 1200Z/22 April 2000

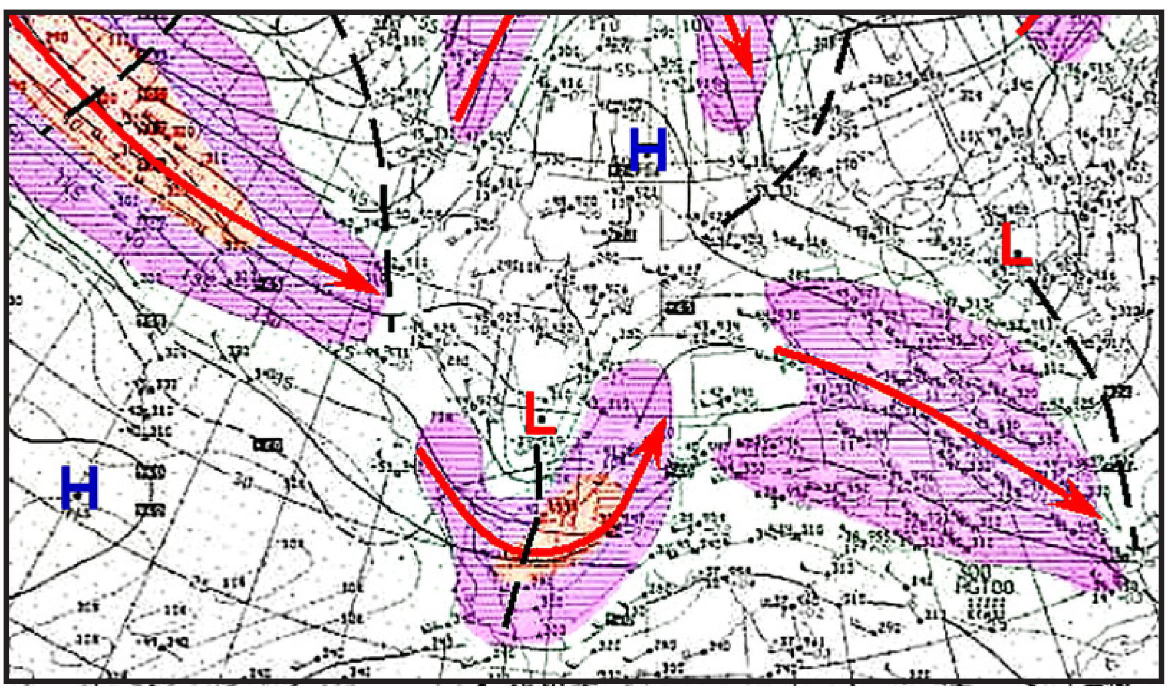

Figure 3-59. 300 mb, 1200Z/22 April 2000

Figures 3-60 and 3-61 depict 500-mb and surface conditions favorable for strong surface winds over southern California, Arizona and New Mexico. This pattern follows closely the model examples shown in Figures 3-56 and 3-57.

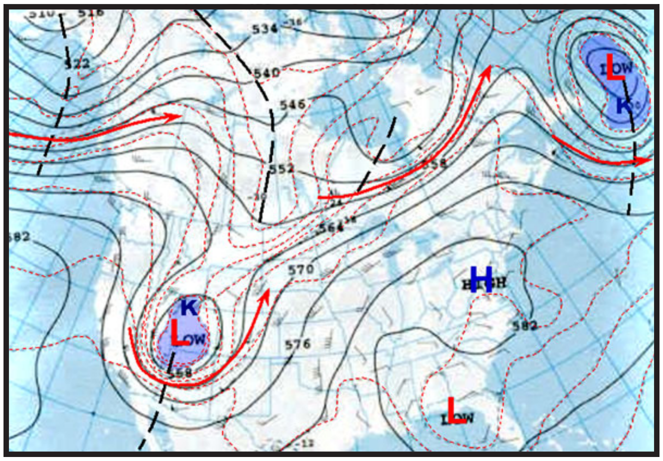

Figure 3-60. 500 mb, 1200Z/3 May 2001.

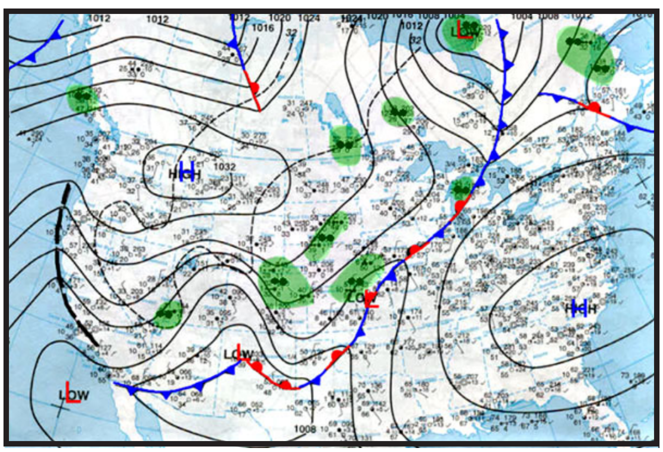

Figure 3-61. Surface, 1200Z/3 May 2001

Utah Box

This wind event occurs when a longwave trough exists near the West Coast and a storm track is established over the Great Basin (Figures 3-62 and 3-63).

An example of the synoptic situation for the *Utah Box* is illustrated in Figures 3-64 and 3-65. In Figure 3-64, a frontal low appears over the Great Basin. At mid-levels (Figure 3-65) a strong southwesterly flow is shown above the Idaho and Utah frontal low.

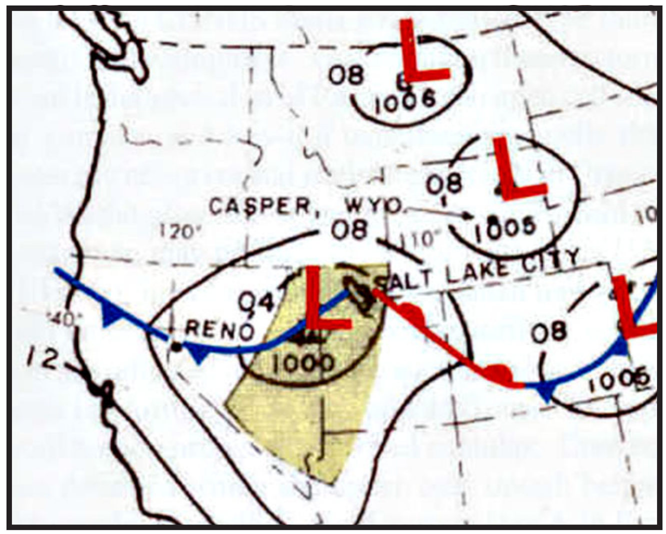

Figure 3-62. Utah Box Surface Example

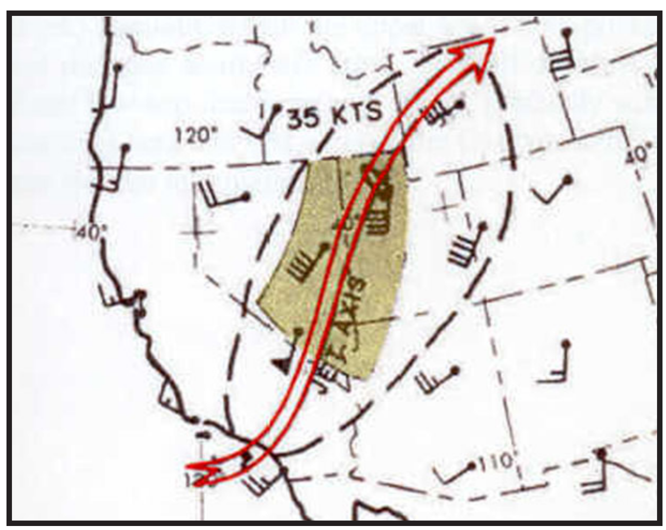

Figure 3-63. Utah Box Mid-Level Maximum Winds.

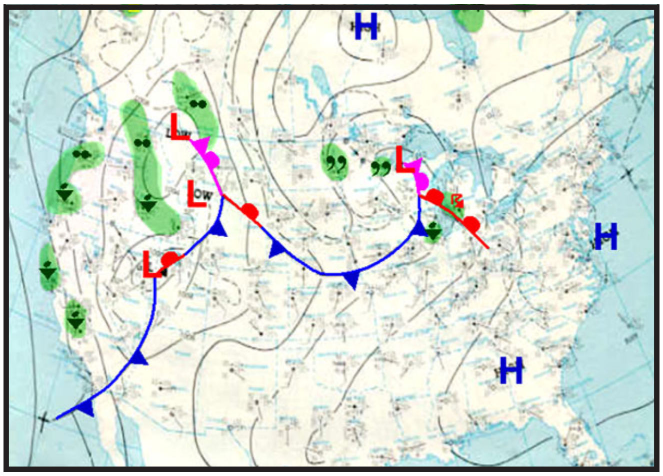

Figure 3-64. Surface, 1200Z/26 March 1981.

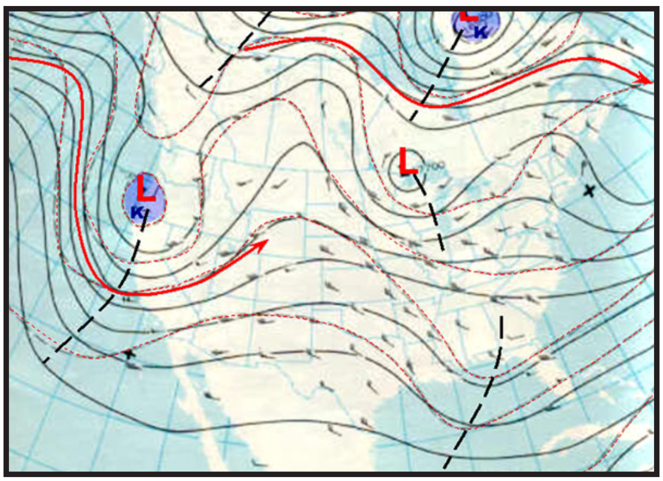

Figure 3-65. 500 mb, 1200Z/26 March 1981.

Livingston Wind Box

A frequent downslope wind event occurs along and east of the Rockies (Figure 3-66). This is just one of several setups for the formation of the *Livingston Box*. Livingston Box wind directions are generally from the southwest. These strong southwest surface winds gradually decrease in strength to the east, away from the mountains.

Strong "cold air advection winds" can also occur within the Livingston Box. Generally northwesterly, these winds do *not* diminish to the east, away from the mountains.

Figure 3-67 shows the reporting stations affected by strong, katabatic winds. The Livingston, Montana (LVM) region is notorious for strong winds that may continue unabated for several days, remaining stronger than 35 knots even during nighttime radiational cooling.

Sometimes, Livingston Box effects will extend southward into northern Colorado, to affect the Denver (DEN) and Boulder (BJC) locations. Malmstrom AFB and the Great Falls National Weather Service Office, both located within the Livingston Box, have developed excellent rules-of-thumb for forecasting strong winds.

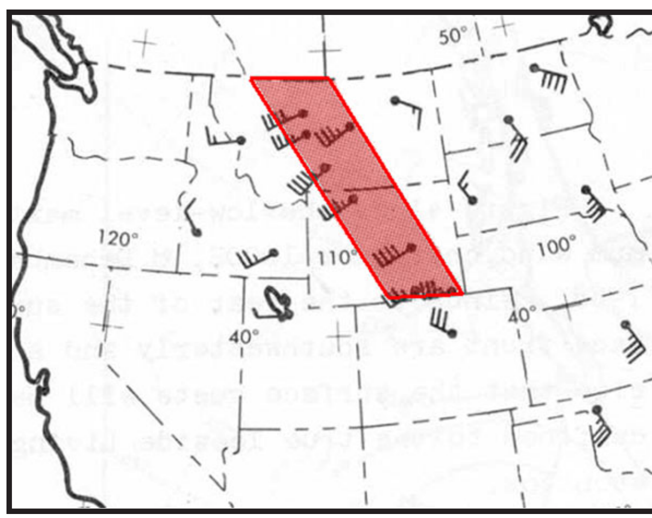

Figure 3-66. Livingston Box

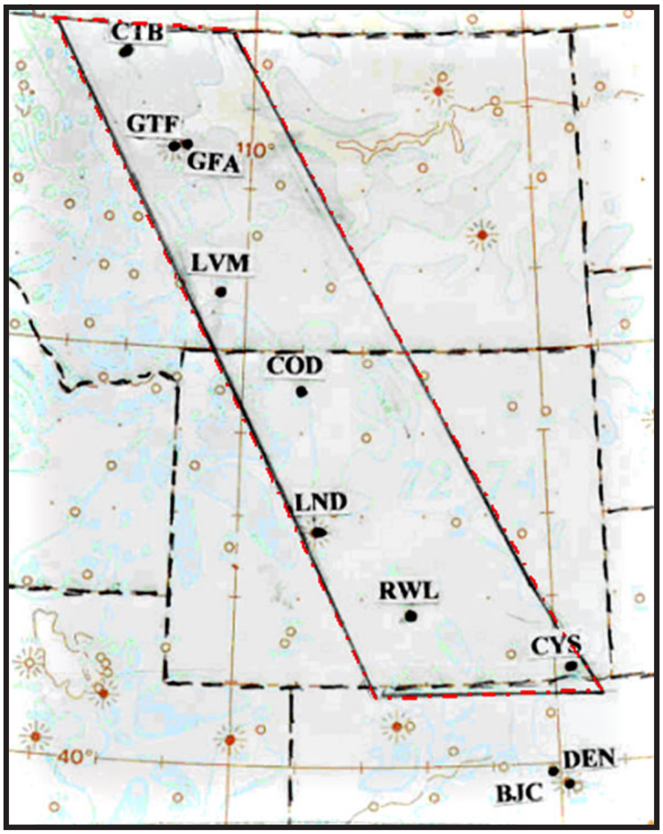

Figure 3-67. Stations in the Livingston Box. Reporting stations affected by strong winds

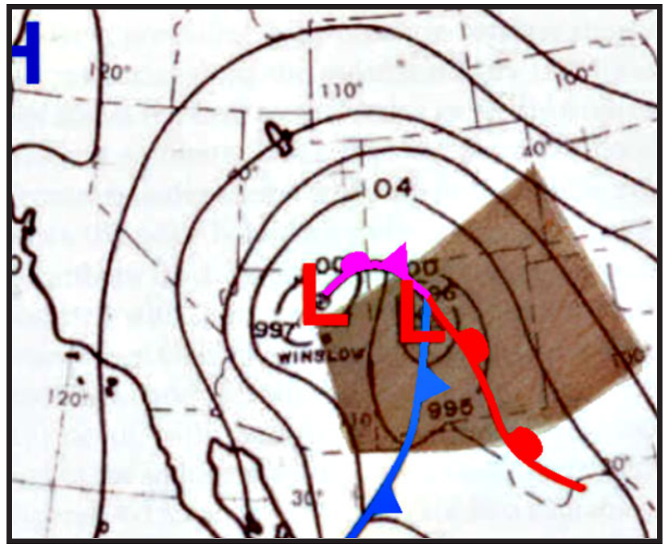

Figure 3-68. Dusty Box Surface.

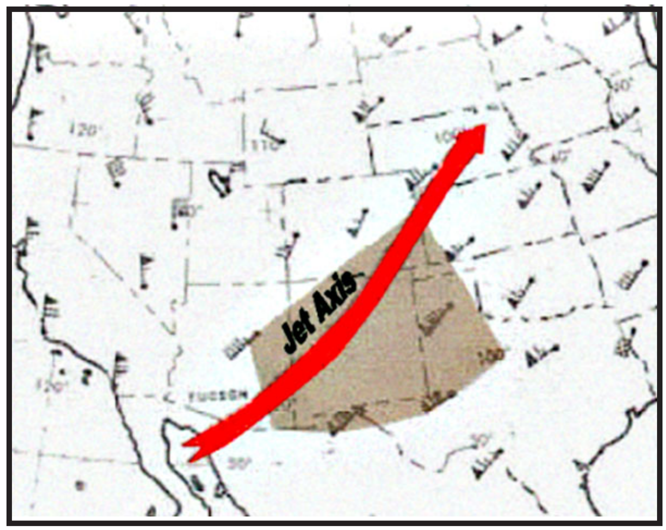

Figure 3-69. Dusty Box Mid-Level Maximum Winds

Dusty Box

The *Dusty Box* occurs often during March through April as low-latitude storm systems move from the southwestern CONUS/southern Rocky Mountains into the southern Great Plains. Strong westerly surface winds will occur from Arizona to western Texas following passage of the cold front of Figure 3-68. Strong southwesterly mid- and upper-level winds associated with a jet streak mix downward to the surface, especially during daytime heating (Figure 3-69). Often, the surface pressure gradient over Arizona and New Mexico is deceptively weak during nighttime cooling, but forecasters need to be aware that strong wind outbreaks may develop during the day. During a strong wind event, and after the storm moves into the Great Plains, visible satellite photos often reveal a dust swath across eastern New Mexico and western Texas (Figures 3-70 and 3-71, note arrows).

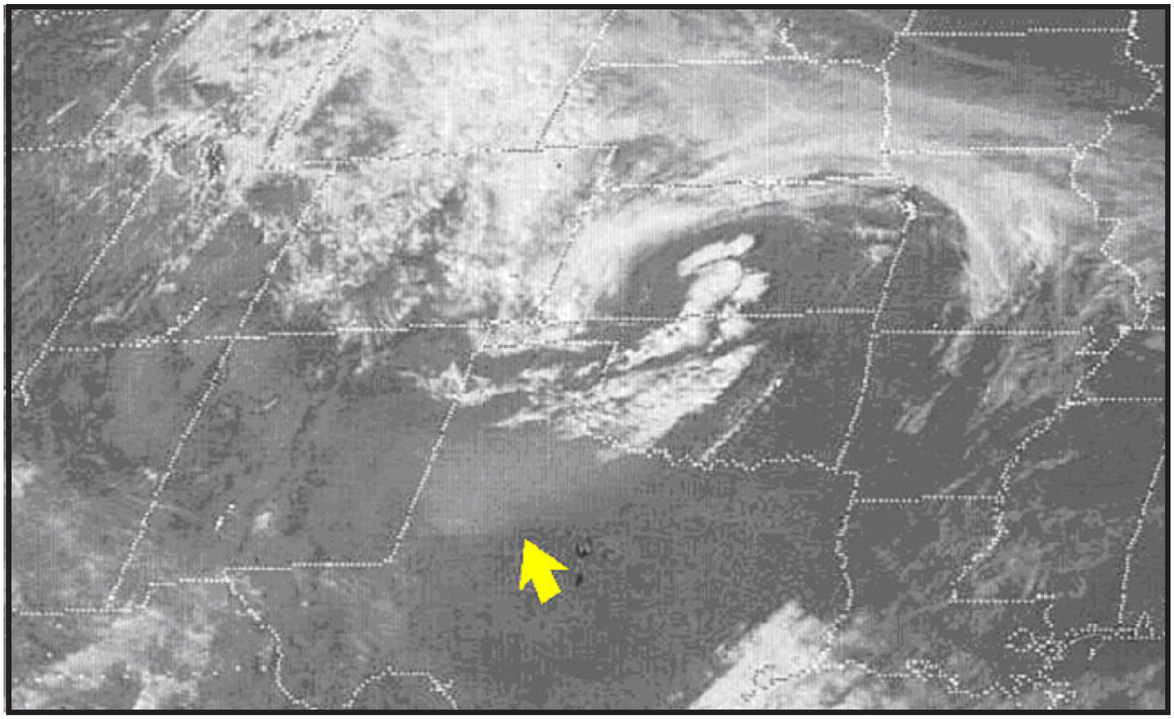

Figure 3-70. GOES E VIS, 2130Z/17 March 1981.

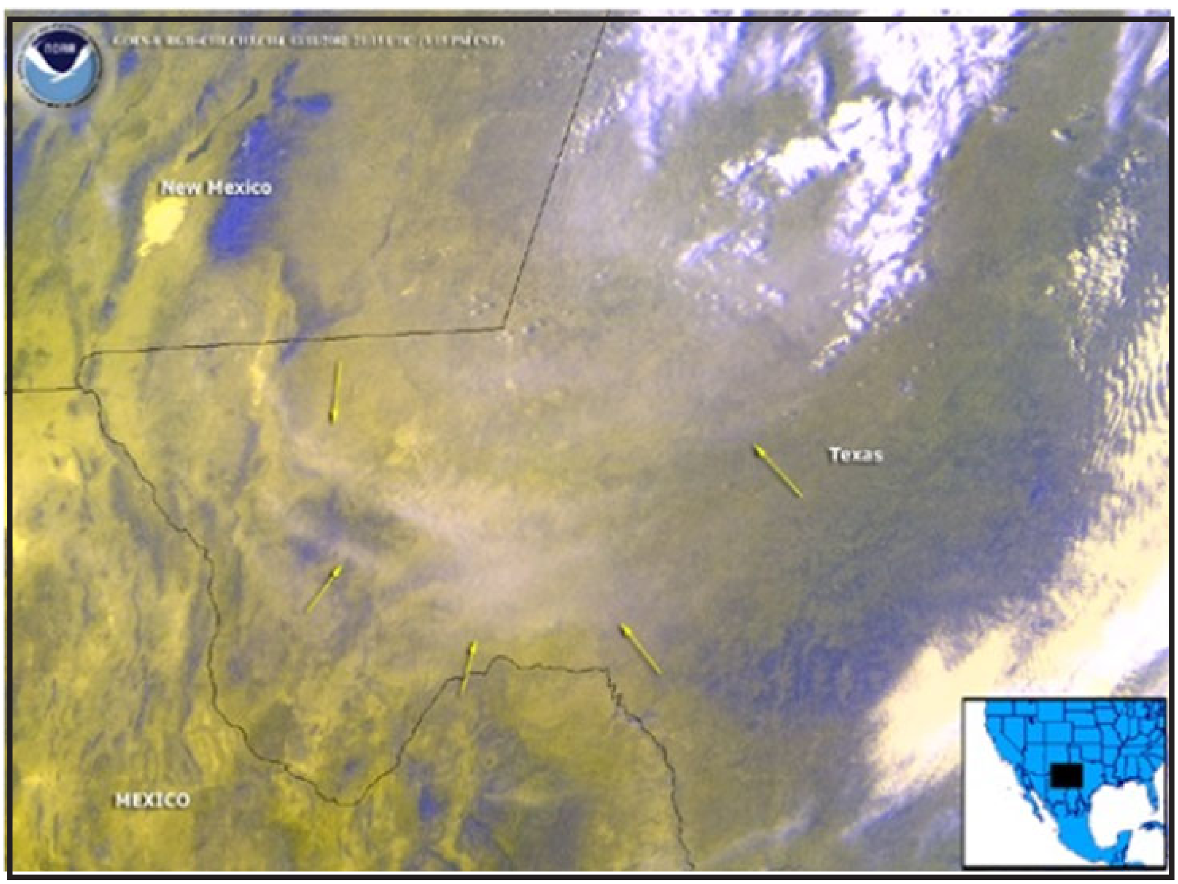

Figure 3-71. GOES E VIS, 2115Z/11 March 2002.

Thunderstorms – Western CONUS

Winter's cold, stable air masses persist through March and mid-April over the western CONUS (associated with the Great Basin High). Pacific mP cold fronts, along with insolation, instability, and orographic lift, provide the ingredients for increased thunderstorm activity beginning in late April. Thunderstorms associated with upper closed lows/troughs over the eastern Pacific may continue through March and early April, affecting coastal locations. By May, a noticeable increase in daytime thunderstorm frequency over heated interior land areas of the western CONUS is likely (Figures 3-72 and 3-73).

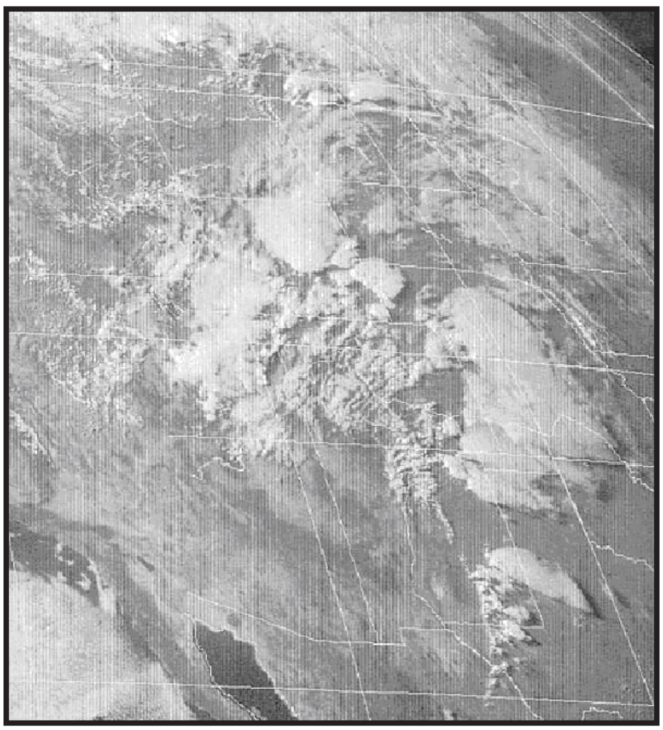

Figure 3-72. GOES W VIS, 0030Z/20 May 1999.

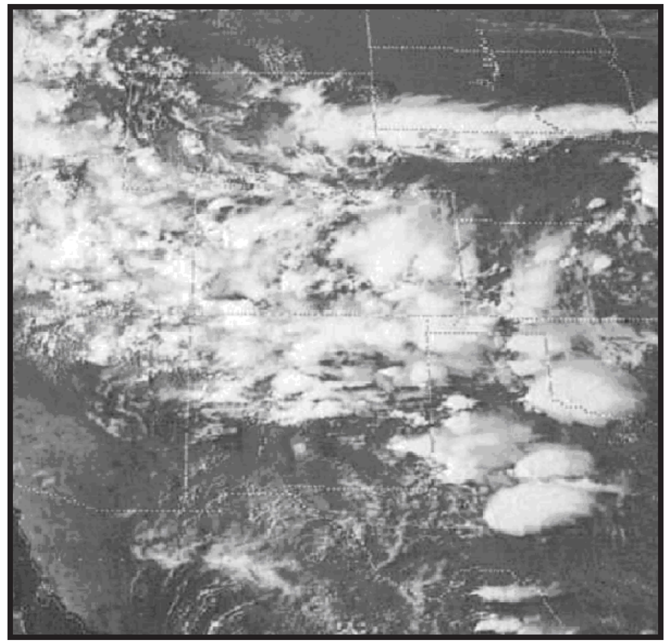

Figure 3-73. GOES W VIS, 2320Z/19 May 1985. Extensive convection across the Great Basin and southern Rocky Mountains.

Monsoon Thunderstorms

The summertime monsoon's effects may begin in late spring. This event is popularly known as the *Arizona Monsoon Season*. The season usually begins by mid to late June when a longwave ridge establishes itself over the central Great Plains. Mid-level southerly winds on the backside of the ridge advect subtropical moisture northward. Figures 3-74 and 3-75 illustrate two examples of the onset of monsoon thunderstorms during mid-June (For more detail, see *Summer Regimes*).

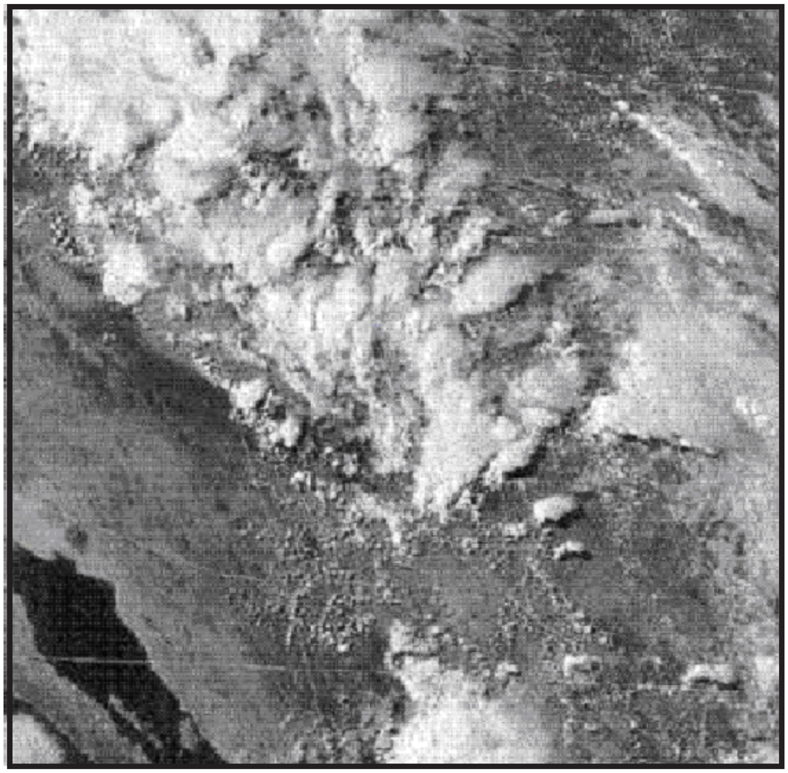

Figure 3-74. GOES W VIS, 2346Z/21 June 1999.

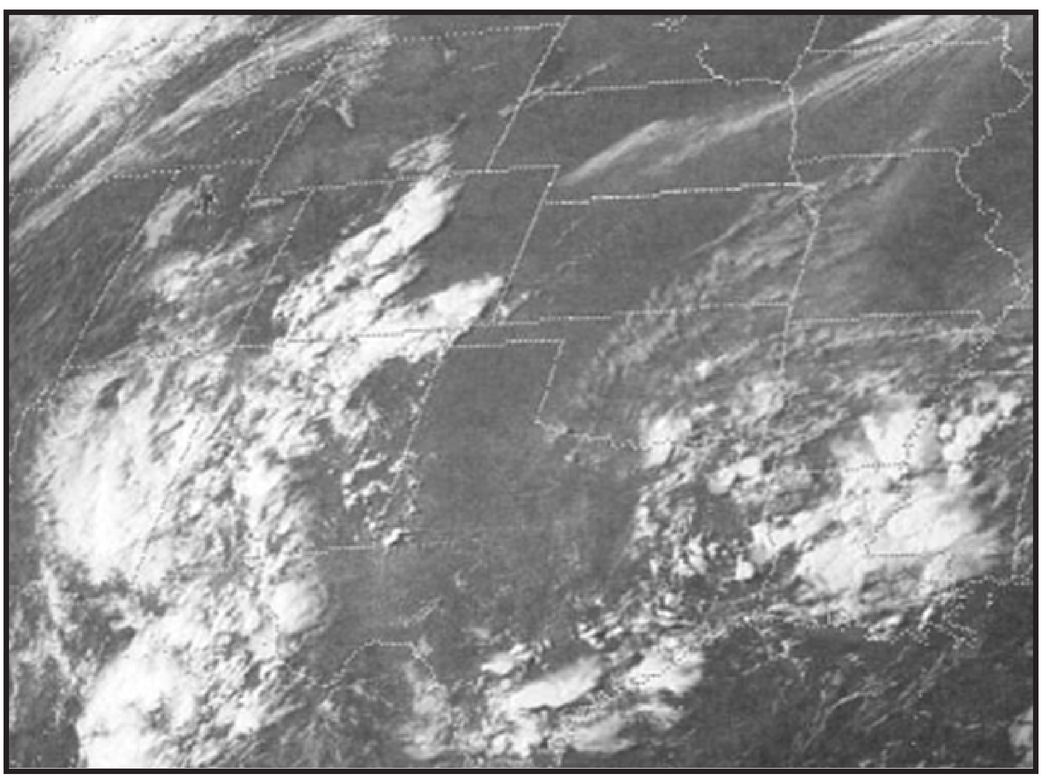

Figure 3-75. GOES E VIS, 2231Z/22 June 1983.

Front Range Thunderstorms

East of the Front Range of the Colorado and Wyoming Rocky Mountains is a prime area for spring thunderstorm development. Moist southeasterly low-level winds, Pacific mP frontal systems, and orographic lift combine to generate thunderstorm lines (Figure 3-76).

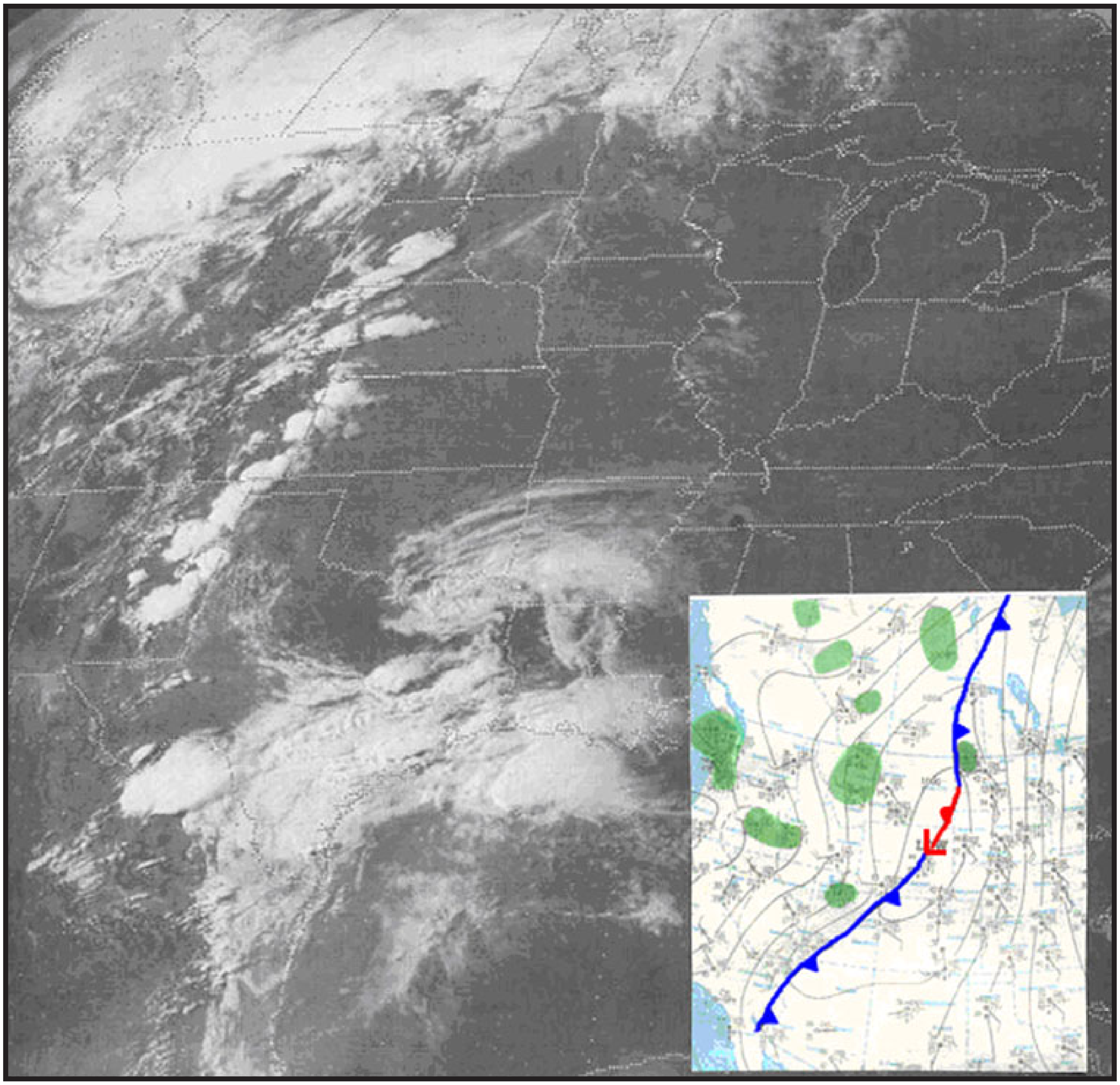

Figure 3-76. GOES E VIS, 2230Z/09 May 1983. The inset shows the surface conditions at 1200Z (approximately 10 hours earlier than the satellite image). A cold front is moving into western Wyoming and Colorado.

CENTRAL CONUS

All of the information presented so far relates to analyses, satellite interpretation and empirical rules. Very little model forecast data has been presented. The intent behind the absence of model guidance is to show that forecasters can produce short term forecasts on their own by analyzing charts and interpreting satellite data.

Short Waves

Short waves that move through primarily zonal flow occur frequently over the CONUS, especially during spring (Figures 4-1 through 4-3). Storm systems that develop within these short waves during the spring season are often intense across the Great Plains and produce many severe weather events.

Central CONUS forecasters should always be suspicious of approaching zonal flow short waves that deepen west of the Rocky Mountains. Significant storms may ensue over the western Great Plains as the following examples illustrate. (Computer models generally excel at predicting trough deepening and cyclogenesis over the western CONUS, warning central CONUS forecasters of impending major storm events.) Early signs of short wave intensification on upper level charts include: cold air advection, digging polar jet, moderate to strong PVA, height fall center movement and a relaxing of height gradients on upper level charts.

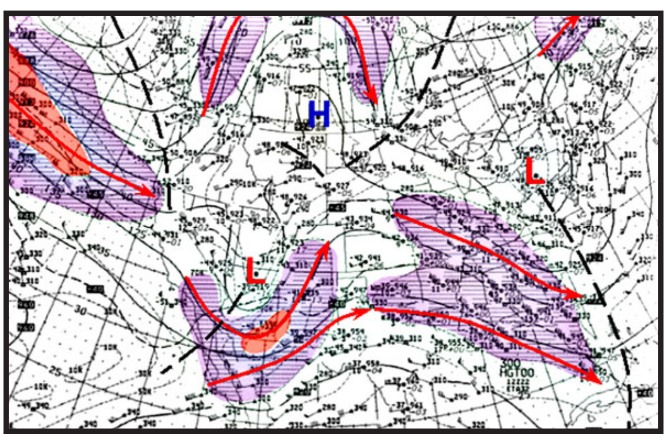

Figure 4-1. 300 mb, 1200Z/22 April 2000

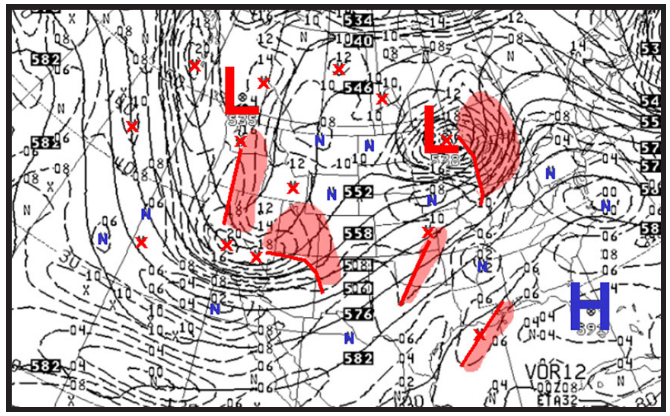

Figure 4-2. 12HR 500 MB HEIGHTS/ VORTICITY, 0000Z/8 April 2001.

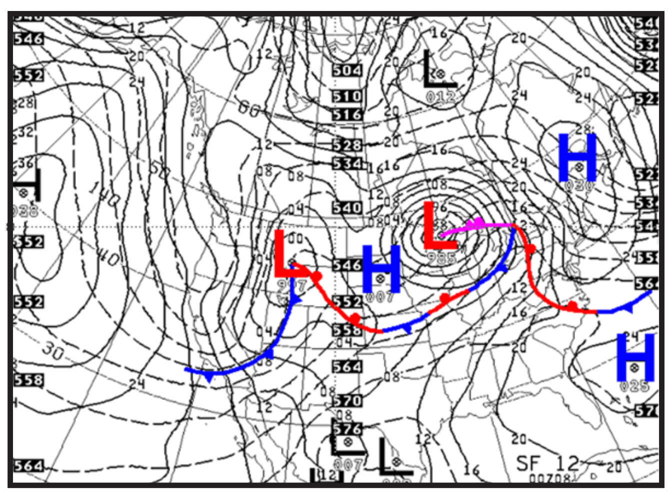

Figure 4-3. 12HR MSL PRES/1000-500 MB THKNS, 0000Z/8 April 2001. See Figure 4-2.

Long Waves

Large-scale meridional troughs and ridges with strong temperature gradients and jet stream support become infrequent in March and generally terminate by early April (Figure 4-4). However, relatively weak longwave trough/ridge couplets occasionally appear into June, before the subtropical ridge/high regime of mid-summer. Figure 4-5 shows a longwave trough/ridge over the CONUS in late spring. Note that intense short waves might briefly resemble longwave troughs as they move eastward.

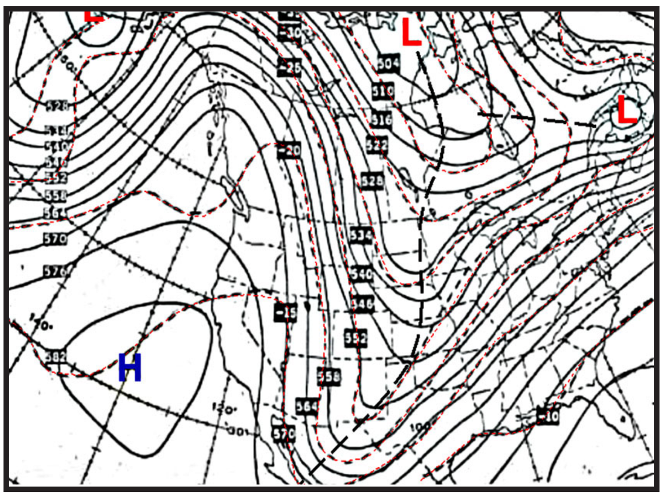

Figure 4-4. 500 mb, 1200Z/Early April Large-scale trough and ridge systems.

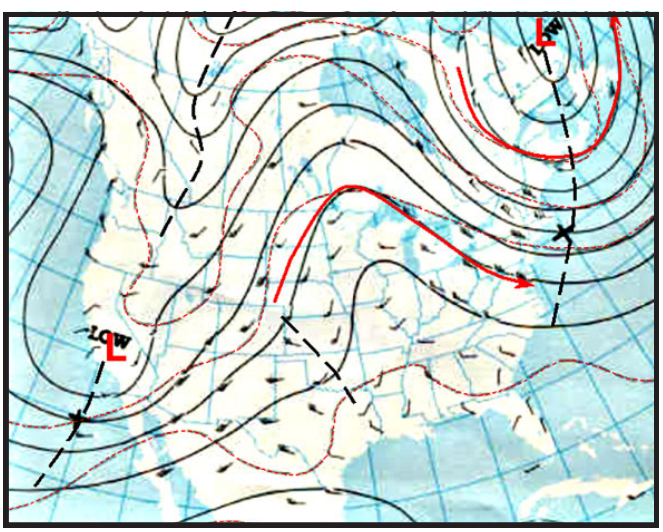

Figure 4-5. 500 mb, 1200Z/28 May 1980

Fronts/Air Masses

Maritime Polar (mP) Fronts

As shown in previous chapters, more Pacific mP cold fronts will track across the Great Plains and eastward (Figure 4-6).

Many storms that intensify on the lee side of the Rockies are associated with mP frontal systems. In Figure 4-7, the upper Great Plains storm system developed over western Kansas along a stationary mP front during the past 24 hours. More examples will be presented later in this chapter.

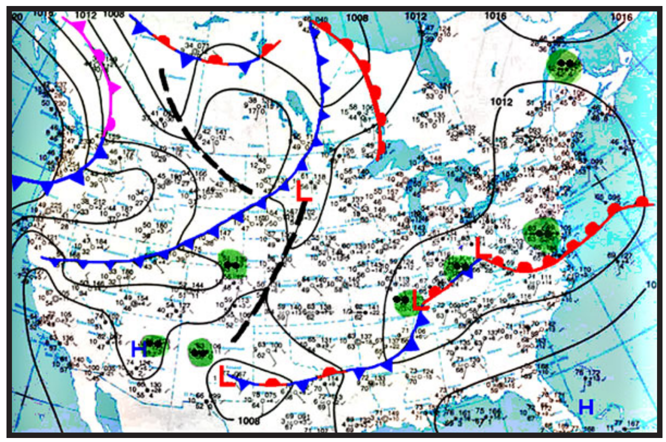

Figure 4-6. Surface, 1200Z/19 May 2001

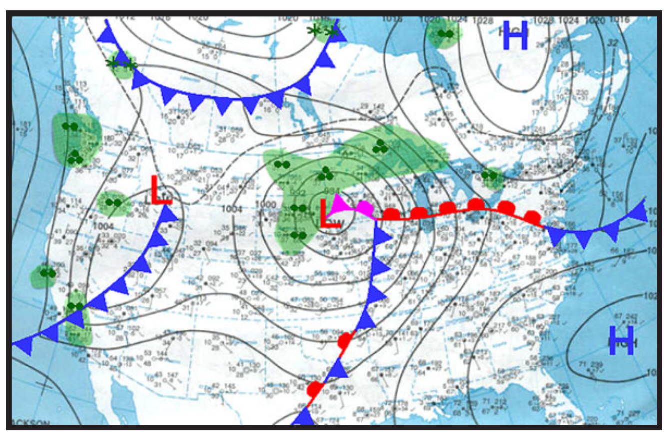

Figure 4-7. Surface, 1200Z/7 April 2001 Another Pacific mP frontal system moving into the Great Basin region.

Continental Polar (cP) Fronts

The winter regime of Canadian air masses, affecting large areas of the central and eastern CONUS, continues through March and April as shown in Figures 4-8 and 4-9. Outbreaks of cP air are likely, although not as frequent, through May as illustrated in Figure 4-10.

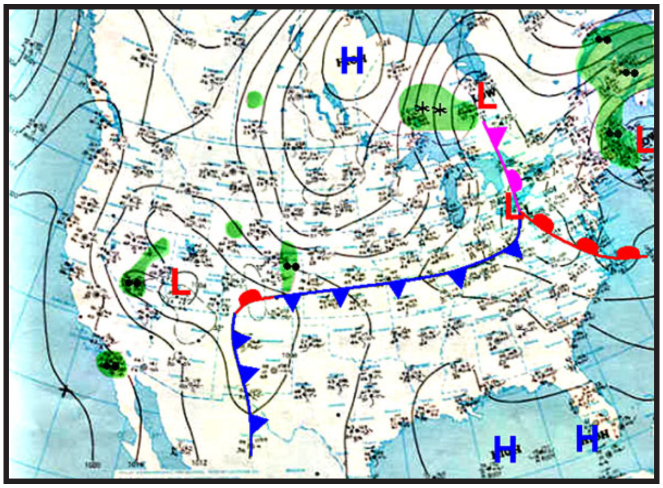

Figure 4-8. Surface, 1200Z/23 April 1980

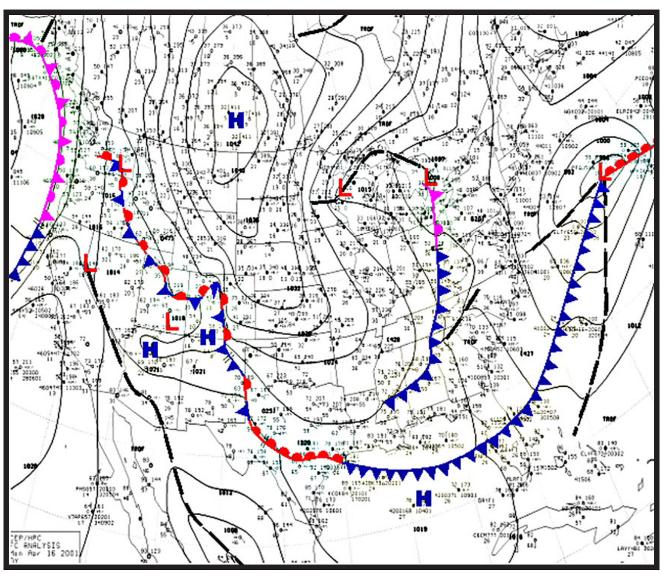

Figure 4-9. Surface, 1800Z/16 April 2001. Continental polar air mass has pushed into the Gulf of Mexico.

Frontal Interaction

The combination of a stationary cP front, aligned east-to-west across the central and northern CONUS, and

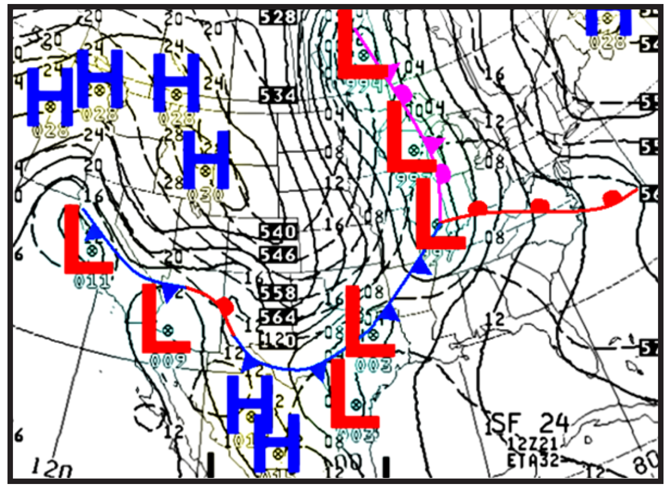

Figure 4-10. ETA 24 Hour, 1200Z/21 May 2001. Tight east-west pressure gradient across the Great Plains is bringing cP air southward.

an eastward-moving mP front over the western CONUS, may eventually produce a Rocky Mountain storm system. Figure 4-11 depicts the initial development of a major storm over Colorado and New Mexico. The associated short wave over the southwestern CONUS (Figure 4-12) enhanced cyclogenesis over the southern and/or central Rockies.

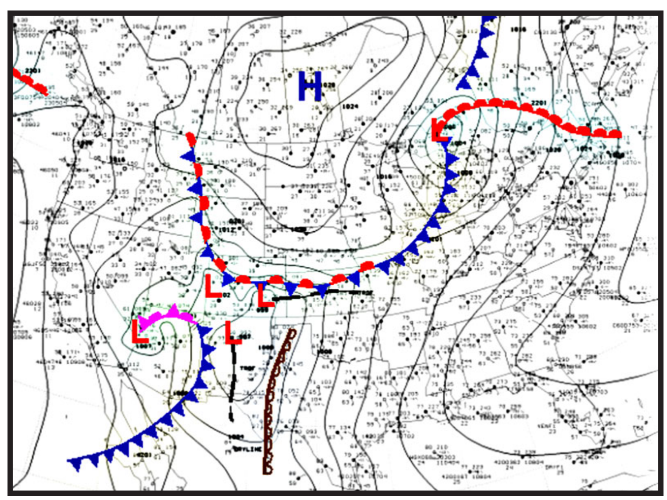

Figure 4-11. Surface, 0000Z/22 April 2001. Gulf moisture overrunning cP/mT stationary front. The mP front and associated short wave provides the energy for Rocky Mountain cyclogenesis.

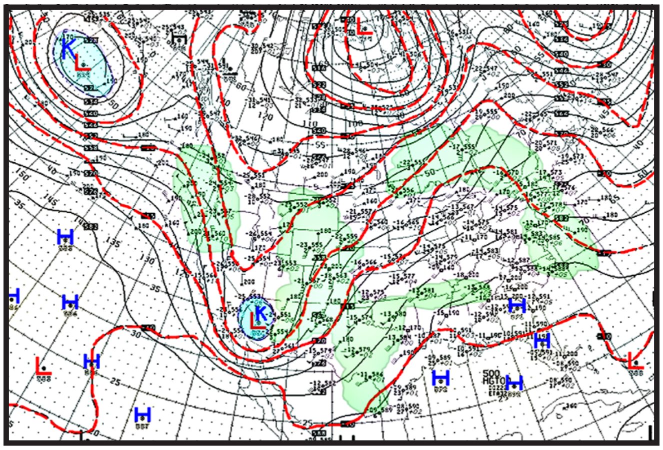

Figure 4-12. 500 mb, 0000Z/22 April 2001. Ideal short wave track across the southwestern CONUS for future development of central/southern Rocky Mountain storms.

East-West Stationary and Warm Fronts

Anticyclones (and cyclones) track further north across the upper Midwest/Great Lakes region by late spring, as the main jet stream shifts northward. Consequently, cold fronts align east-west and often become stationary across the central and southern plains. Frequently, warm moist Gulf air flows northward and overruns the front (Figures 4-13 and 4-14).

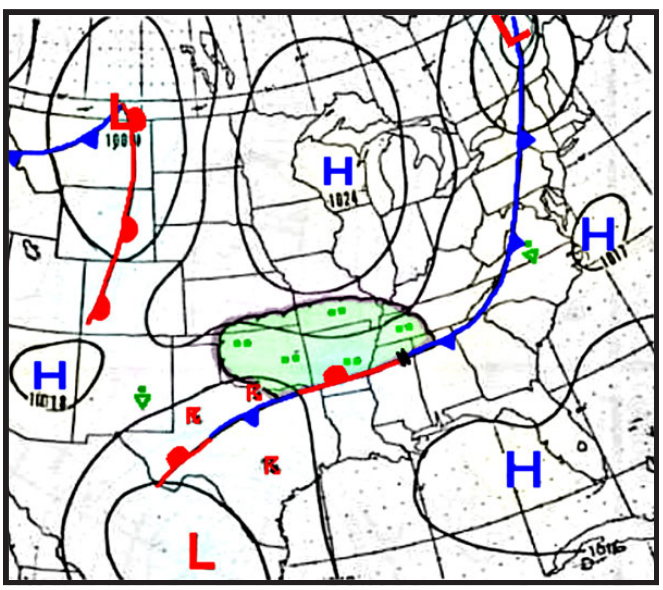

Figure 4-13. Surface, 1800Z/21 May 1979

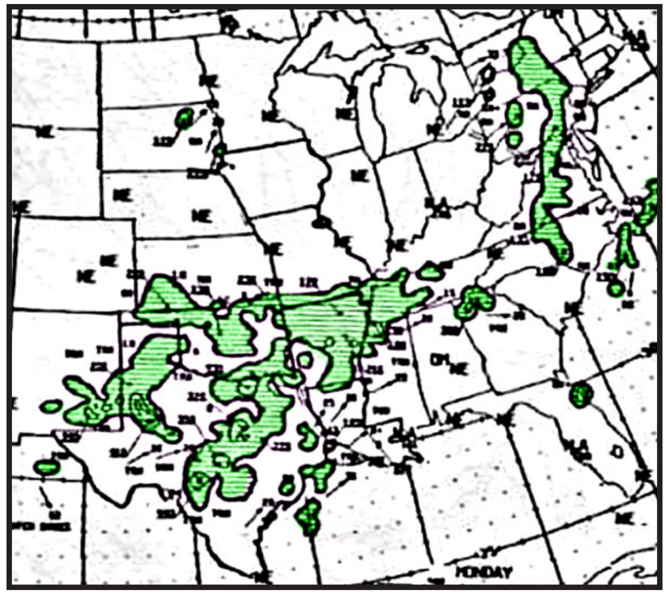

Figure 4-14. Radar Summary Chart, 1735Z/21 May 1979. One-half hour earlier than Figure 4-13.

Often, thunderstorms and widespread precipitation develop along these stationary fronts prior to the arrival of a Rocky Mountain storm system. An example is shown in the satellite image in Figure 4-15. North of the warm front, an extensive area of cloudiness stretches across the Great Plains. The arrow marks Gulf moisture advection. By mid-afternoon, thunderstorms broke out over northeastern Texas and central Oklahoma within the Gulf moisture band ahead of the cold front, and also north of the warm front where lifting and surface heating helped destablize the air mass. Warm frontal thunderstorms developed further to the north into Kansas and eastern Missouri later in the afternoon.

During winter and continuing through spring, cold fronts that have pushed into Texas and the Gulf Coastal region (Figure 4-16) often become stationary. In time, these stationary fronts began to lift northward and become warm fronts as the associated anticyclone moves to the East Coast (Figure 4-17).

Figure 4-17 depicts a late spring/summer event where a cP front becomes stationary over the central CONUS. The air mass within the frontal zone becomes increasingly unstable. Southerly, moist winds overrun the stationary front, creating a favorable environment for thunderstorms (Figure 4-18).

Sometimes, warm fronts over the southern Great Plains appear to dissipate as airmass modification blurs the frontal boundary. Consider placing the front further north across the central Great Plains, where stronger airmass discontinuities exist. This is especially true if cyclogenesis is occurring along an approaching mP cold front over the central and southern Rocky Mountains.

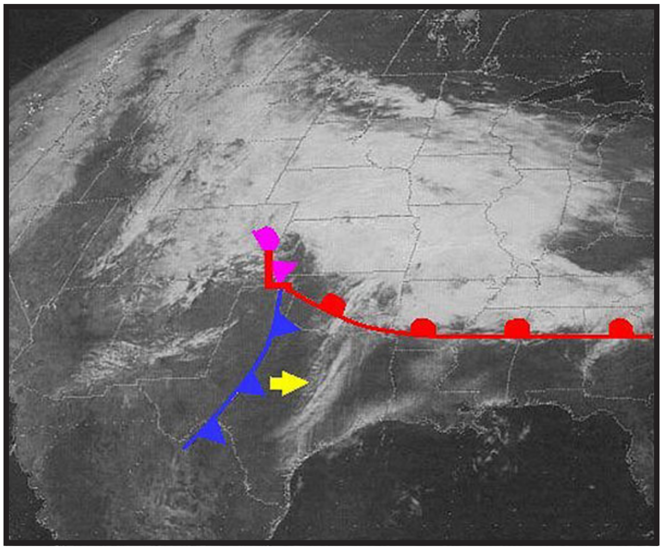

Figure 4-15. GOES E VIS, 1730Z/17 May 1981. Extensive cloudiness north of the warm front. Arrow marks a band of Gulf moisture advection.

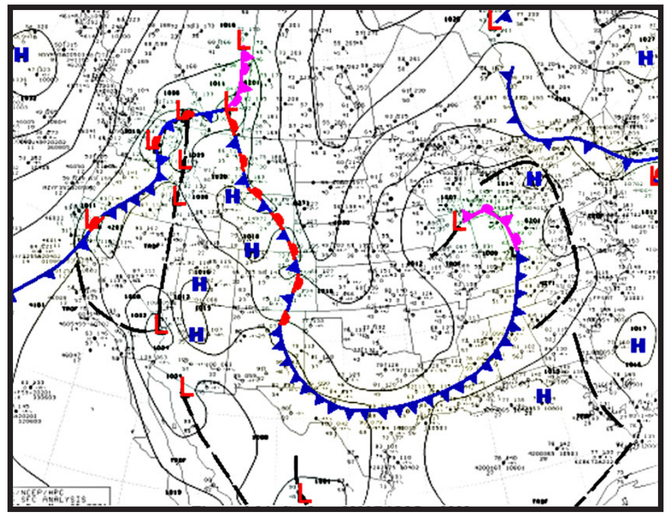

Figure 4-16. Surface, 0000Z/25 May 2001

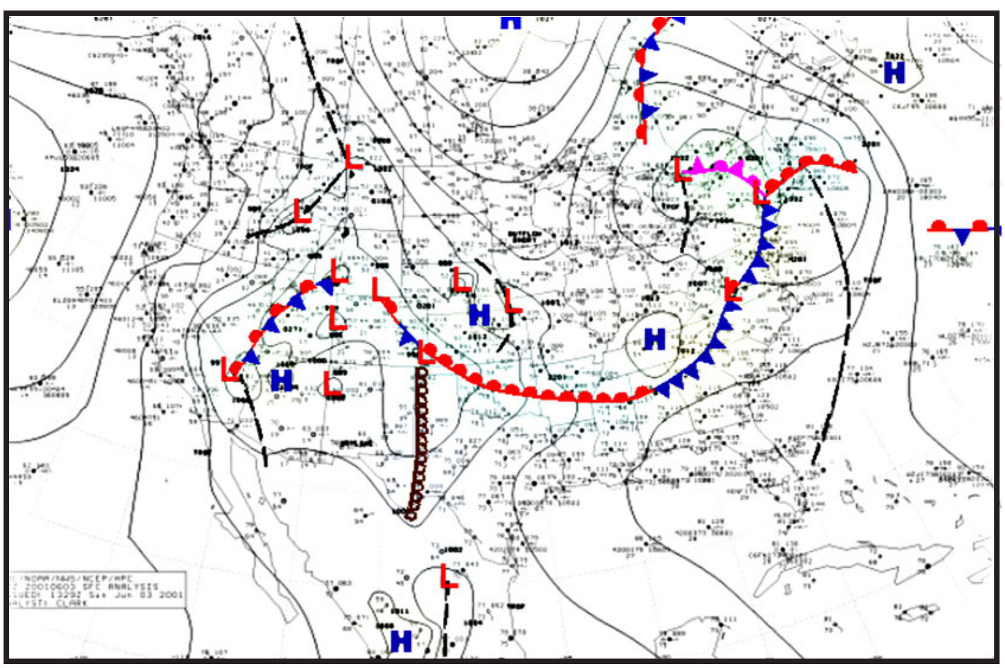

Figure 4-17. Surface, 1200Z/3 June 2001

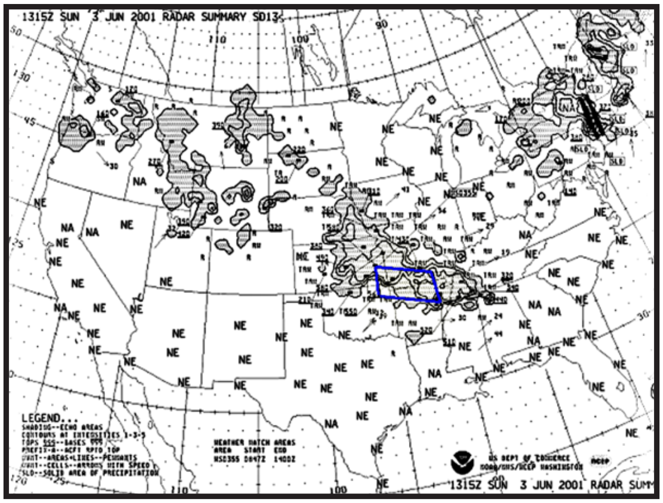

Figure 4-18. Radar Summary, 1315Z/3 June 2001. Extensive overrunning along and north of a warm front over the central Great Plains with numerous embedded thunderstorms. The severe thunderstorm axis over southern Missouri and northern Arkansas probably coincides with the nose of the low-level jet.

Figure 4-19 depicts an east- to-west stationary cP/mT frontal boundary. Thunderstorms have developed along the boundary. Abundant moisture advection (indicated by convection south of the front) will likely continue and increase the convection's severity and areal coverage. By mid-May central and northern Plains forecasters will experience more of these cold fronts "hanging up" over their region.

Figure 4-20 depicts another example. The occluded low over the northern plains and southern Manitoba/ Ontario became "hung up" due to a blocking ridge to the east. The cold front over the central CONUS has become stationary (Figure 4-20, inset). Convection has developed along the front from Missouri to New York. Gulf moisture from Texas to Missouri (noted by the arrow) will provide additional moisture for continued thunderstorm activity (and severe thunderstorms). This example is a typical mid to late spring event where convection develops along stationary fronts within a moist, heated and unstable atmosphere.

During late spring and continuing through summer, placing frontal systems--especially warm fronts--across the southern and central Great Plains can be difficult. During the cold winter months, sufficient air mass discontinuity exists that warm fronts are easily identified. During the spring months, identification becomes increasingly more difficult, as the milder mP replaces the colder cP as the dominant "cold" airmass type, resulting in weaker temperature discontinuities.

Forecasters must analyze in detail minor changes in the wind, moisture and thermal fields in order to locate these boundaries. Thunderstorms will develop (often rapidly) along these weak boundaries when sufficient moisture, instability and heat are in place.

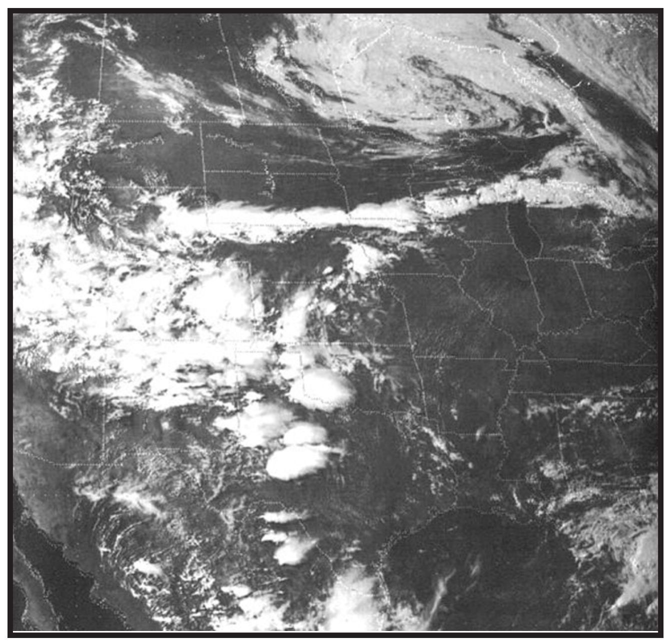

Figure 4-19. GOES E VIS, 2320Z /19 May 1985. Thunderstorms have developed along a stationary cP/ mT front across the northern CONUS.

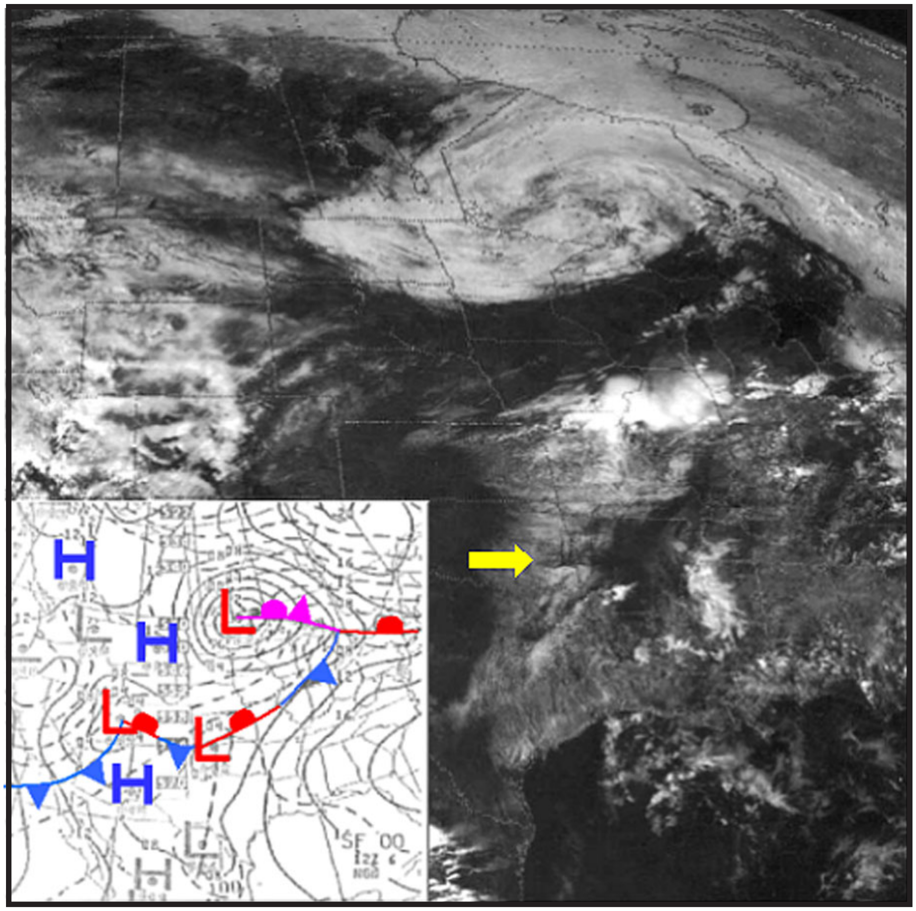

Figure 4-20. GOES E VIS, 2000Z/6 May 1986. Inset: NGM Analysis, 1200Z/6 May 1986

Stationary Fronts Oriented South-to-North

By mid-May, south-to-north oriented maritime polar frontal systems from the western CONUS may become stationary over the Great Plains (Figure 4-21). This regime becomes established when upper level troughs become stationary over the western CONUS. Eastward advancement of associated mP cold fronts comes to a halt as the upper-level flow parallels these fronts.

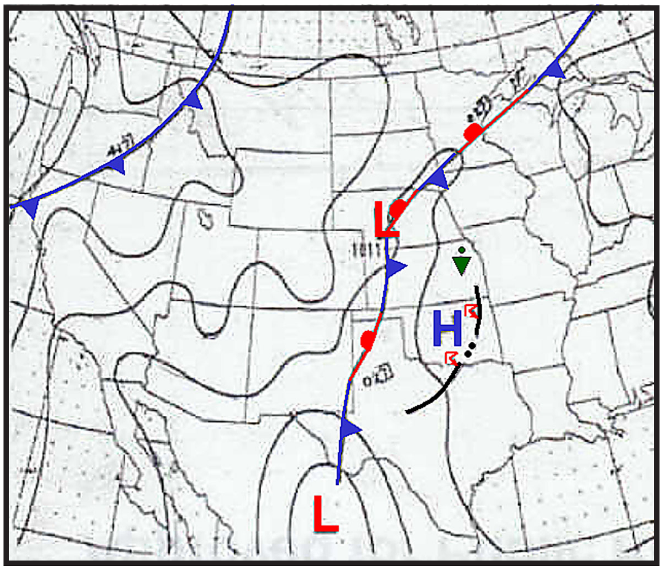

Figure 4-21. Surface, 0600Z/28 May 1978. Thunderstorms develop daily along stationary mP frontal systems east of the Rockies and over the western High Plains. The front remains stationary; however, the thunderstorm line moves eastward as a squall line.

The east-to-west pressure gradient produces the low-level jet that enhances warm moist advection during the approach of an mP front from the Rockies. Look for squall line activity to develop along these stationary fronts during daytime heating; these squall lines will persist for several hours as they move east or northeastward. Low-level jets, associated Gulf moisture tongues, and instability east of these fronts can enhance thunderstorm severity. Tornado activity is not uncommon. This regime is similar to dry-line thunderstorm events. Figures 4-22 through 4-25 depicts an example over a two-day period.

In Figures 4-22 and 4-24, a long wave trough/ridge pattern is shown over the CONUS. The surface features are shown in Figures 4-23 and 4-25.

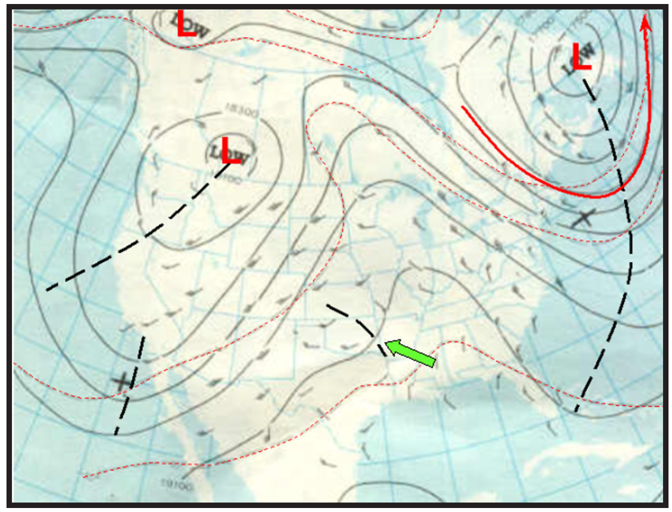

Figure 4-22. 500 mb, 1200Z/ 27 May 1980. A weak southwesterly wind flow is shown over the central CONUS. The arrow notes a weak short wave within the ridge.

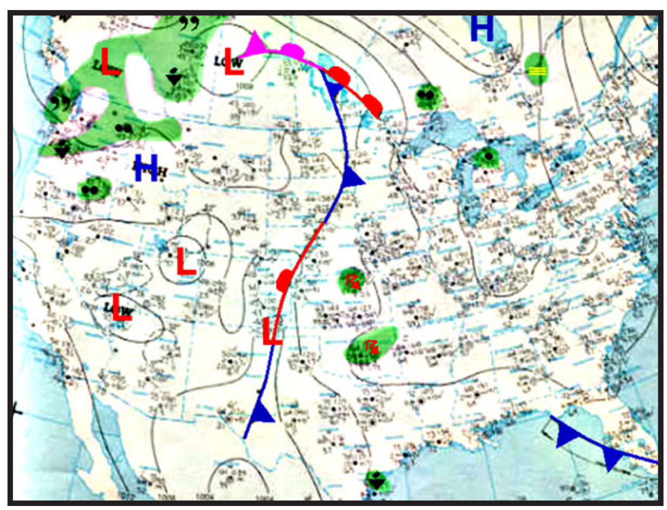

Figure 4-23. Surface, 1200Z/27 May 1980. Maritime polar front has stalled over the western Great Plains. Morning thunderstorms are shown over Kansas and Oklahoma associated with the short wave and the stationary front (ref. Figure 4-22).

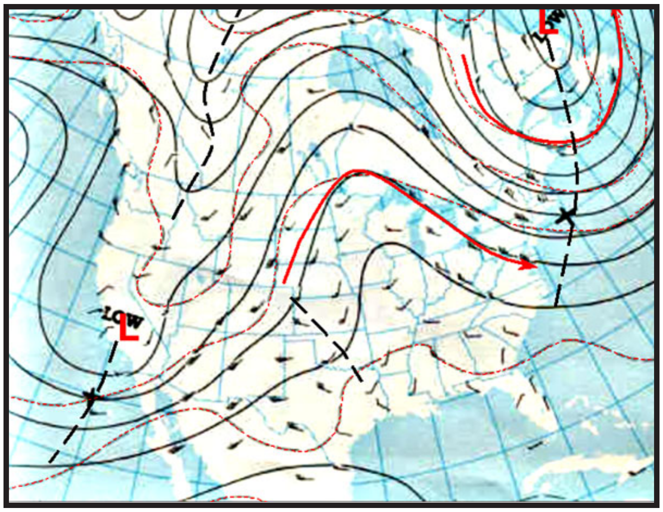

Figure 4-24. 500 mb, 1200Z/28 May 1980. Twenty-four hours after Figure 4-22. Little change from 24 hours ago. Weak short wave within the ridge over the central Plains continues east of the stationary front. These weak short waves should not be ignored; they will enhance thunderstorm activity.

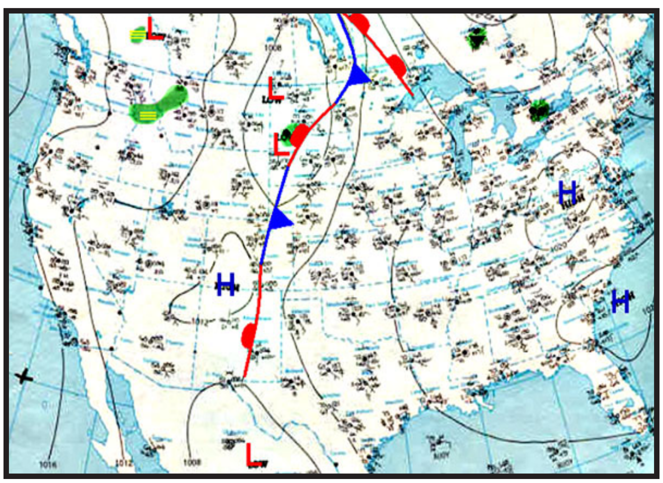

Figure 4-25. Surface, 1200Z/28 May 1980. Twenty-four hours after Figure 4-23. The front remains stationary east of the Rocky Mountains.

Storm Tracks

Canadian and Northern Rocky Mountain Cyclogenesis

This regime normally occurs during winter (Alberta Lows) but may continue through late March and early April, and is generally associated with a longwave trough/ridge regime. This regime ends by mid-April when zonal flow short waves and Rocky Mountain/Great Plains cyclogenesis become the dominant regimes (presented next). Two examples will be shown in Figures 4-26 through 4-34. In the first early spring event, Figure 4-26, a longwave trough prevails from the Rocky Mountains to the East Coast. A short wave is located over western Canada (Fig. 4-26, arrow) and will likely drop southeastward into the northern Rockies and Great Plains. The associated polar frontal low is over western Canada (Figure 4-27).

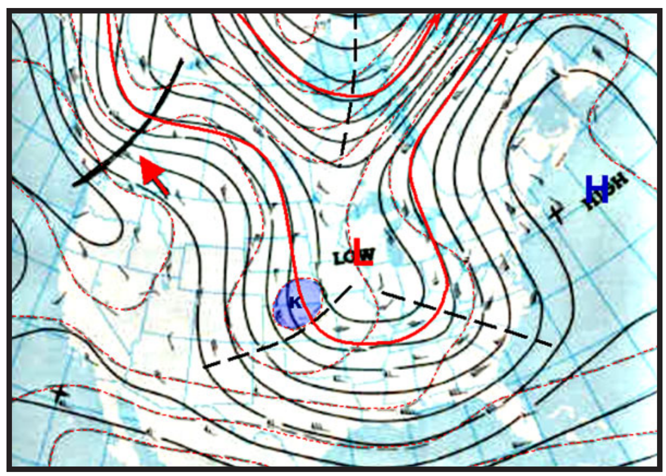

Figure 4-26. 500 mb, 1200Z/24 March 1979

In Figure 4-28, twenty-four hours later, the short wave has dropped into the southern Canada/northern Rocky Mountain region. At the surface (Figure 4-29) the associated storm system appears over the northern Rockies and Great Plains. In this regime, snow and strong surface winds would likely affect an area from eastern Montana to the Great Lakes.

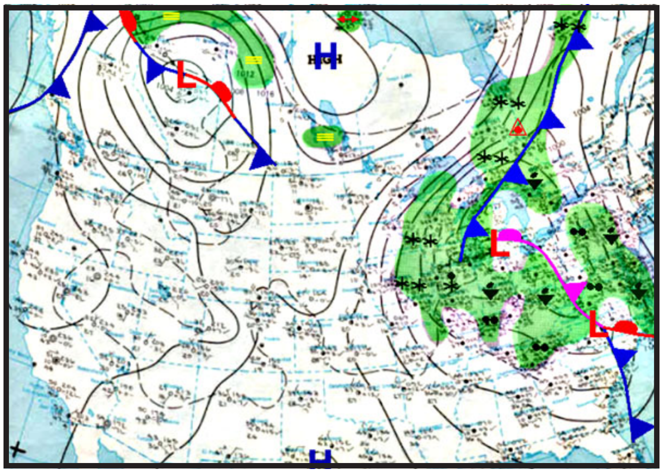

Figure 4-27. Surface, 1200Z/24 March 1979

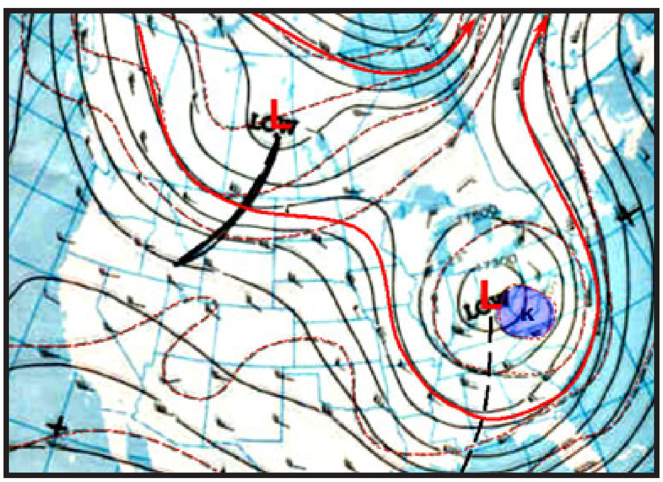

Figure 4-28. 500 mb, 1200Z/25 March 1979

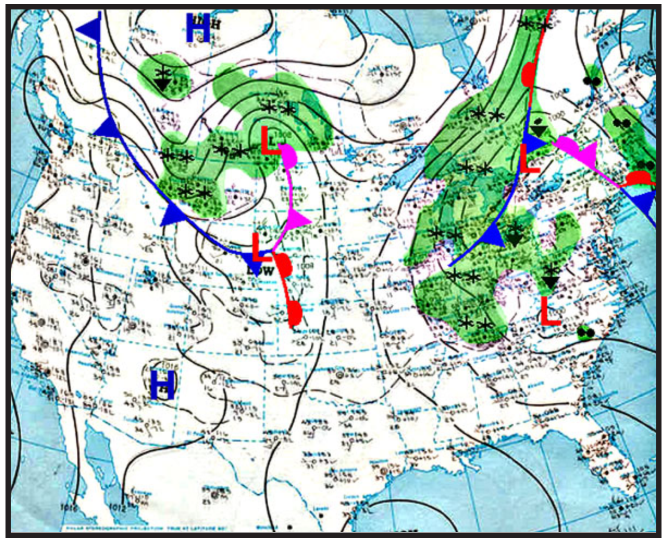

Figure 4-29. Surface, 1200Z/25 March 1979

A second event is shown in Figures 4-30 through 4-34. A longwave trough is noted over the eastern Canada/CONUS region. A northwest-southeast wind flow across the central and western CONUS will channel Pacific short waves over the northern Rockies and Great Plains (i.e. Alberta Lows). In Figure 4-30a, a positive vorticity advection (PVA) lobe is barely noticeable within the height contours over western Canada. In Figure 4-30b a polar frontal wave is forecast in the same area. The developing low moved rapidly southeastward supported by strong mid- and upper-level polar jet streaks.

Figures 4-31a and b depict the ETA model's 36-hour forecasts (24-hours after Figures 4-30a and 4-30b). PVA and the surface polar frontal wave are forecast to strengthen as they move rapidly southeastward. This *Alberta Low* regime brings strong surface winds and snow to the upper Great Plains followed by blasts of fresh CP air (Figure 4-31b).

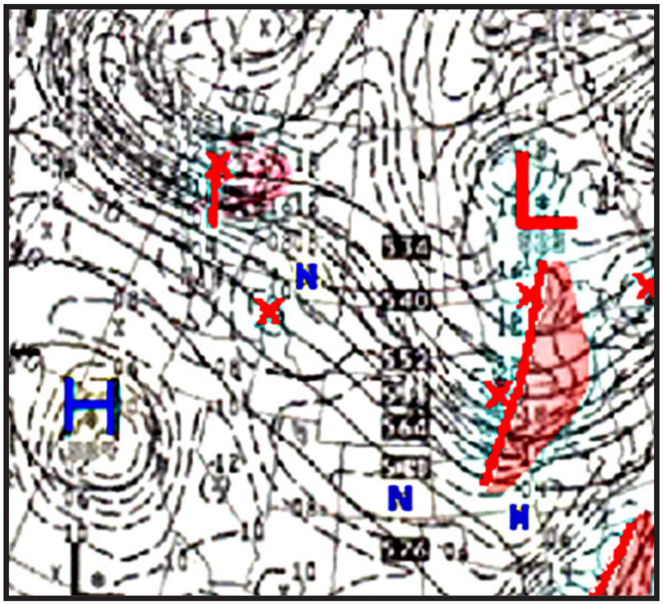

Figure 4-30a. ETA 12HR 500 MB HEIGHTS/ VORTICITY, 1200Z/31 March 2002.

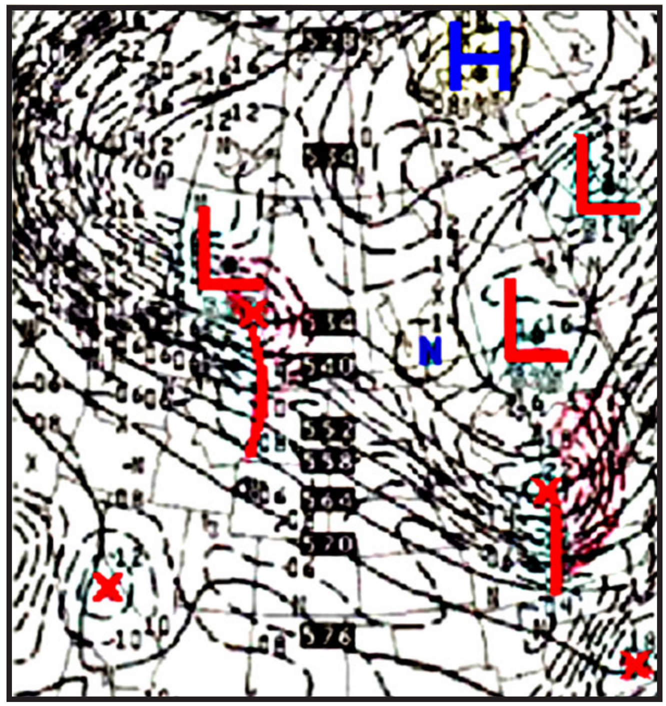

Figure 4-31a. ETA 36HR 500.MB HEIGHTS/ VORTICITY, 1200Z/1 April 2002.

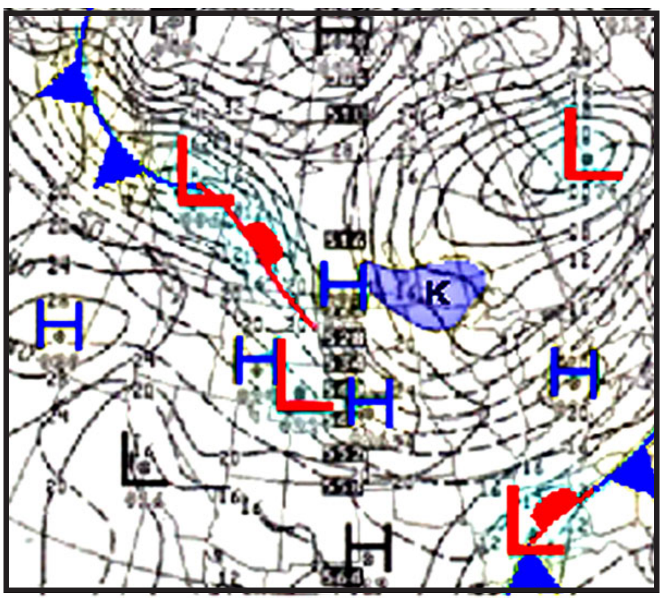

Figure 4-30b. ETA 12HR MSL/PRES 1000-500 THCKNS, 1200Z/31 March 2002.

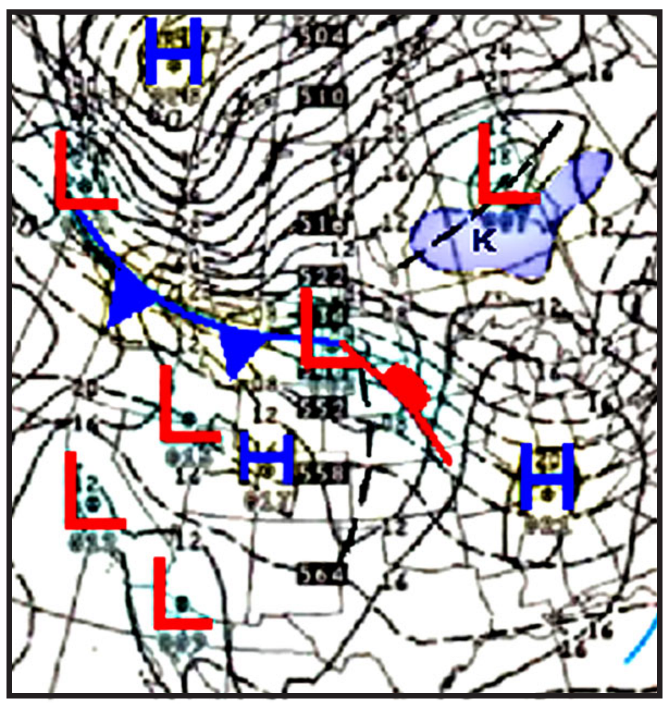

Figure 4-31b. ETA 36HR MSL/PRES 1000-500 THCKNS, 1200Z/1 April 2002.

Figures 4-32 and 4-33 depict the verifying surface analyses. In Figure 4-33, warm frontal snow has developed over North Dakota. Upslope snow is occurring within an easterly low-level flow over the Montana Rockies.

The weather depiction analysis, Figure 4-34, (one hour later than Figure 4-33) shows that warm frontal snow has developed southeastward into southern Minnesota and northeastern Iowa. Upslope snows continue over the Montana Rockies.

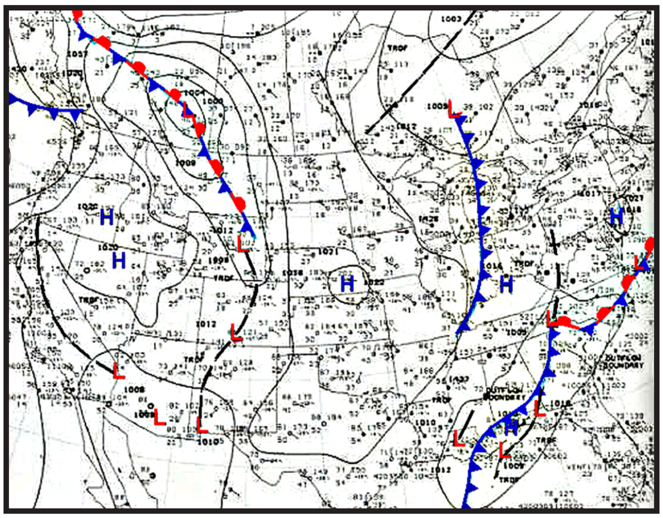

Figure 4-32. Surface, 2100Z 31 March 2002.

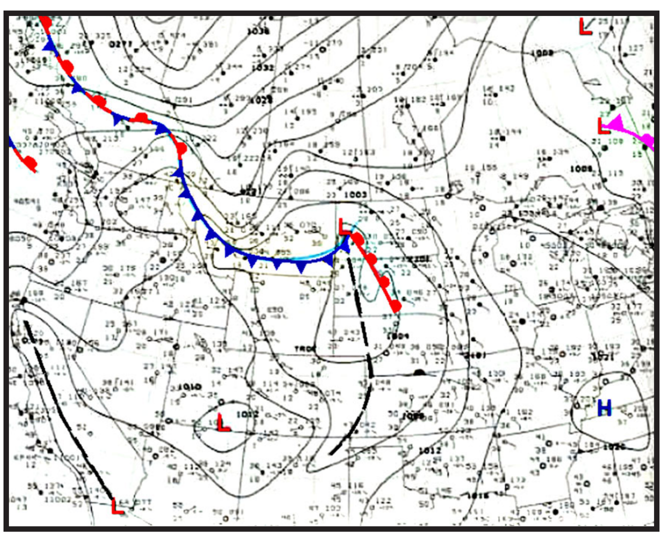

Figure 4-33. Surface, 1200Z/1 April 2002.

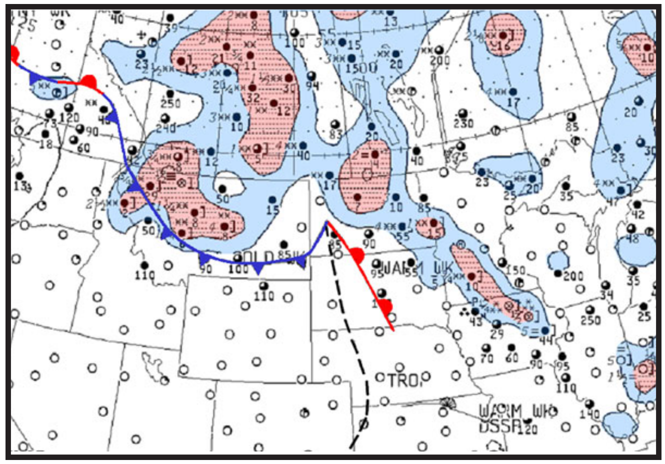

Figure 4-34. Weather Depiction, 1300Z/1 April 2002.

Finally, one more snow event that occurred in late May 2002 is shown in Figures 4-35 through 4-38.

Central and Southern Rocky Mountain Cyclogenesis

Colorado Low – Springtime Snowstorms

Continuing a wintertime trend, significant storm development along the east slopes of the Rocky Mountains, producing significant snowfall over the Rockies and the western Great Plains, is likely through April. Thunderstorm events, often severe, become a major forecasting problem across the Great Plains when these deepening lows emerge from the Rocky Mountains.

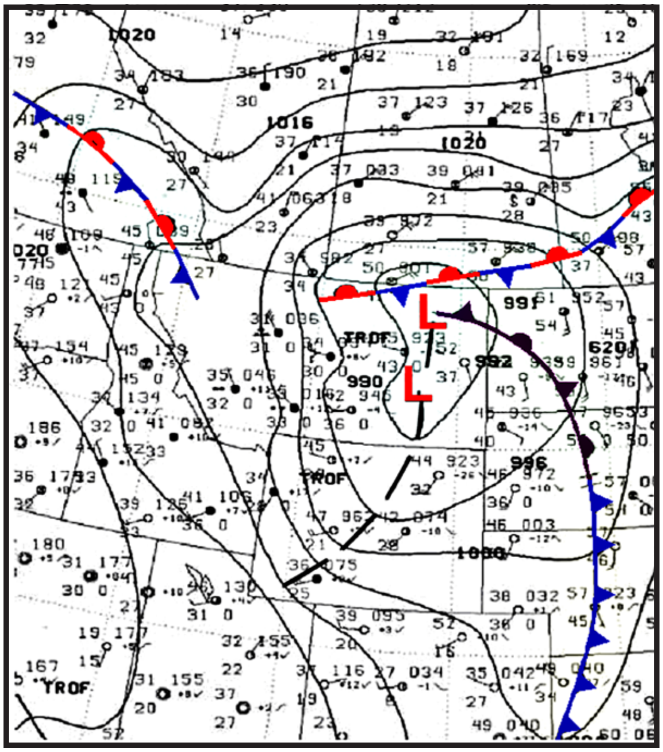

Figure 4-35. Surface, 1200Z/22 May 2002

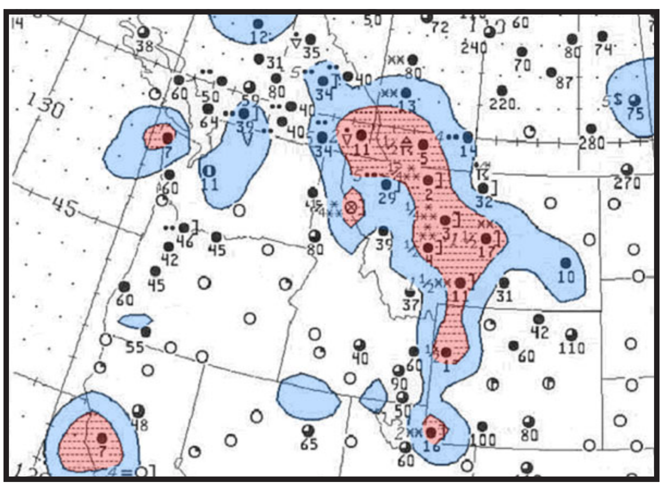

Figure 4-36. Weather Depiction, 1300Z/22 May 2002

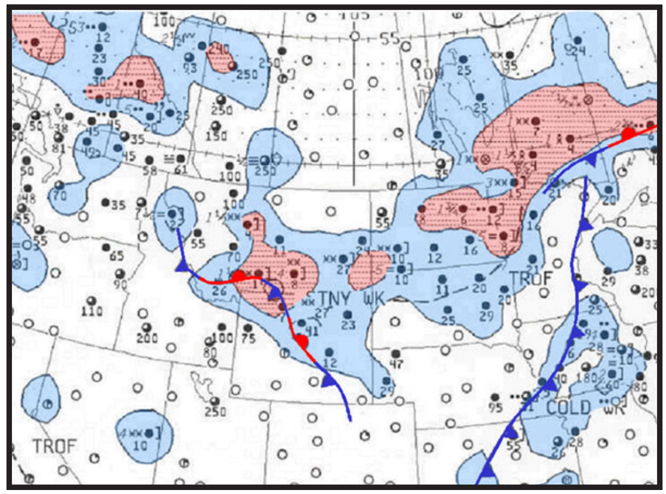

Figure 4-37. Weather Depiction, 1300Z/23 May 2002.

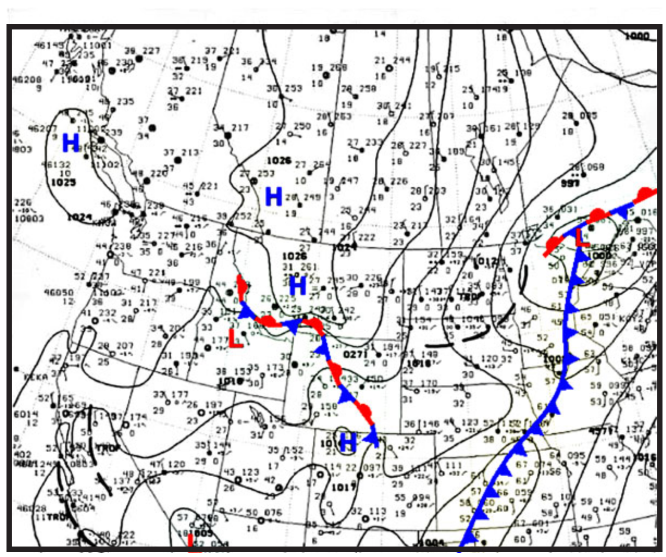

Figure 4-38. Surface, 1200Z/23 May 2002

Surface lows frequently develop within the lee-side trough, mainly over eastern Colorado (Colorado Low Regime). Figure 4-39 illustrates a synoptic regime (*receding-high* regime) that occurs often across the Great Plains. There will be many variations to this regime. Migratory cP highs from Canada or mP highs that have crossed the Rocky Mountains modify as they move eastward toward the Atlantic Ocean. Return southerly flow advects warmer, moister air northward ahead of the next developing disturbance. Clouds and precipitation increase rapidly when Gulf moisture advects northward and interacts with upper-level impulses that have moved into the Western Plains. This regime is characterized by short waves in primarily zonal flow.

We present several case studies, since this cyclogenesis regime occurs frequently over the Great Plains (frequently associated with a receding high).

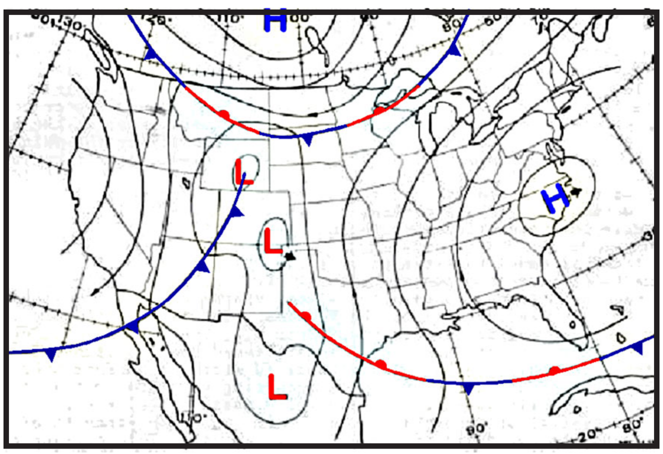

Figure 4-39. Receding High

Example 1 – 11 April 2001

Figures 4-40 through 4-52 include analyses, ETA model forecasts, satellite photos, and radar summaries. The 500-mb analysis (Figure 4-40) typifies the upper air regime for Colorado low development. Note the southwestern CONUS short wave approaching the southern Rockies. The related surface analysis is depicted in Figure 4-41. A dry line precedes the mP cold front over western Texas and eastern New Mexico.

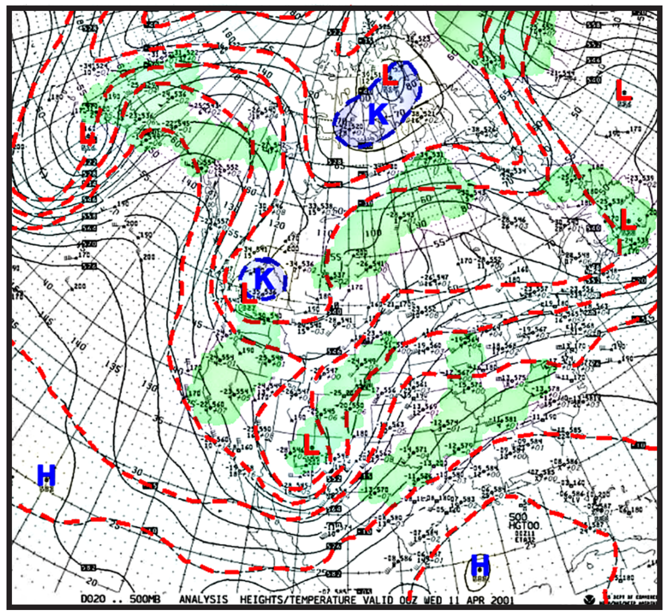

Figure 4-40. 500 mb, 0000Z/11 April 2001

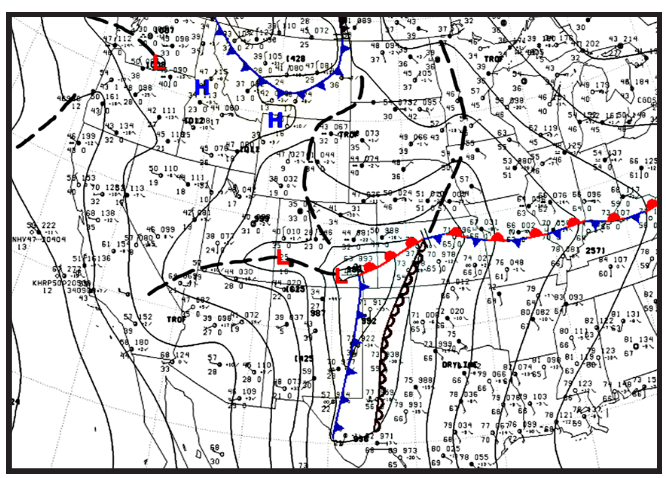

Figure 4-41. Surface, 0000Z/11 April 2001. Primary surface low located over southeastern Colorado. Continued deepening expected as associated upper low approaches (ref Figure 4-40).

How did the ETA model handle this developing storm system? The model forecast was "right on target" (ref ETA 12-hour through 36-hour forecasts, Figures 4-42 through 4-47). The 12-hour low's forecast position in Figure 4-42 matches the actual location in Figure 4-40. A strong Colorado low is forecast to develop (Figure 4-43).

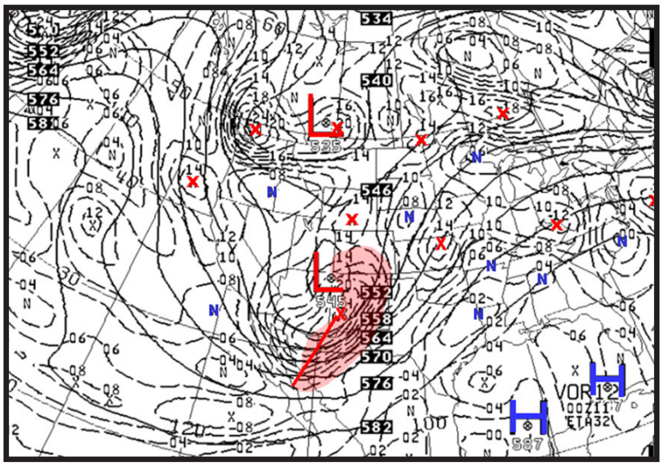

Figure 4-42. 12HR 500 Heights/Vorticity, 0000Z/ 11 April 2001

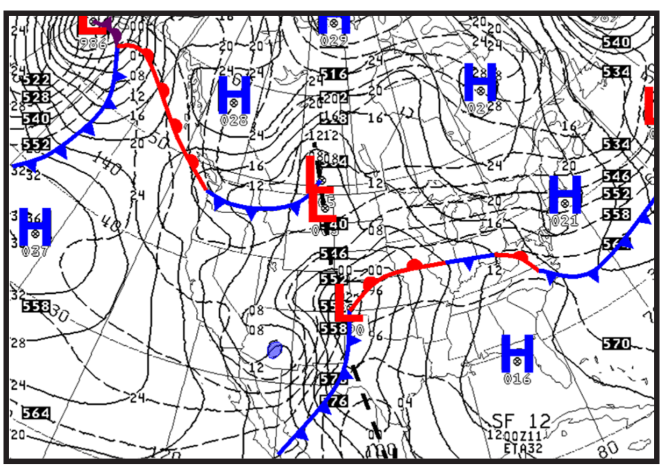

Figure 4-43. 12HR MSL PRES/1000-500MB THICKNESS,0000Z/11 April 2001. Colorado low is intensifying. Tight thickness packing over New Mexico indicates a strong cold front and associated strong surface winds.

Verification of the ETA's 24-hour 500mb forecast (Figure 4-44) is depicted in the visible satellite image (Figure 4-48). The model correctly forecast a large comma system. North and northwest of the surface low, from the Rocky Mountains to western Kansas to South Dakota; this is the likely area of snowfall.

A color-enhanced image of this storm system is shown in Figure 4-49. Note over extreme northeast Texas (arrow) the abrupt change from middle/high clouds (yellow and green) to gray-scale low clouds. This sharp gradient delineates the boundary of strong PVA.

Figure 4-50 depicts a radar image of the cloud system over eastern Colorado and western Nebraska.

In the early morning photo, Figure 4-51, the storm's center is over the western Great Plains. The visible satellite image, Figure 4-52, depicts the snowfall swath with this storm.

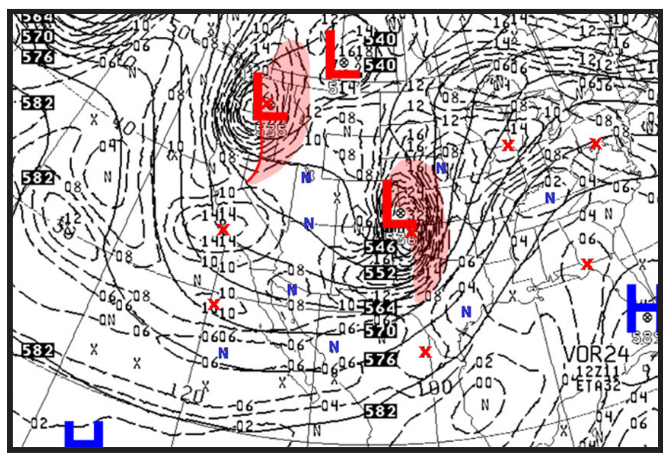

Figure 4-44. 24HR 500MB Heights/Vorticity, 1200Z/11 April 2001. Short wave is forecast to round the base of the longwave trough and move northeastward toward the northern Great Plains.

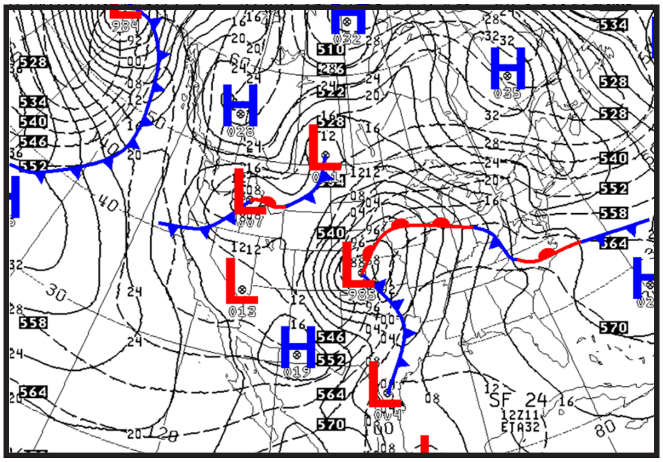

Figure 4-45. 24HR MSL PRES/1000-500MB THKNS, 1200Z/11 April 2001. Not much eastward movement of the Colorado low was forecast during the past 12-hour period (until the upper low catches up and stacks with the surface low). Strong cold advection winds expected within tight gradients over Colorado, New Mexico and the Texas Panhandle.

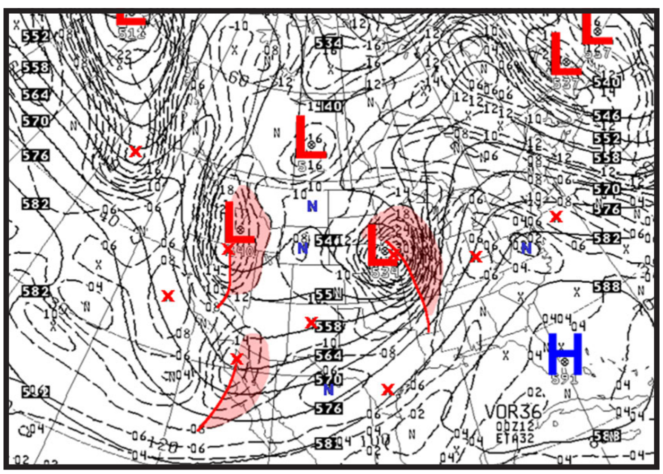

Figure 4-46. 36HR 500MB HEIGHTS/ VORTICITY, 0000Z/12 April 2001. Short wave has lifted northeastward into the northern Great Plains.

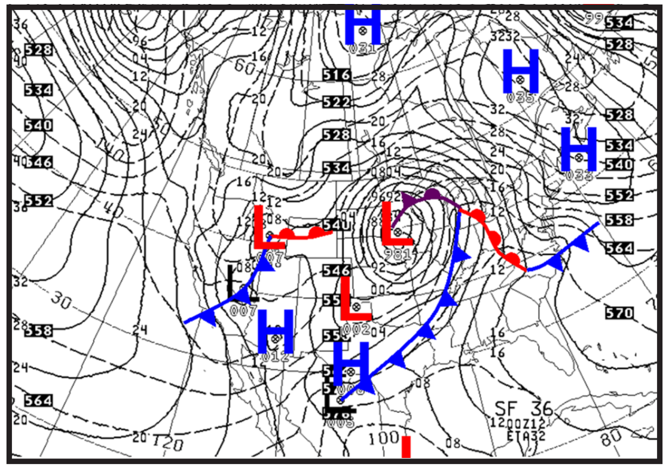

Figure 4-47. 36HR MSL PRES/1000-500MB THCKNS, 0000Z/12 April 2001.

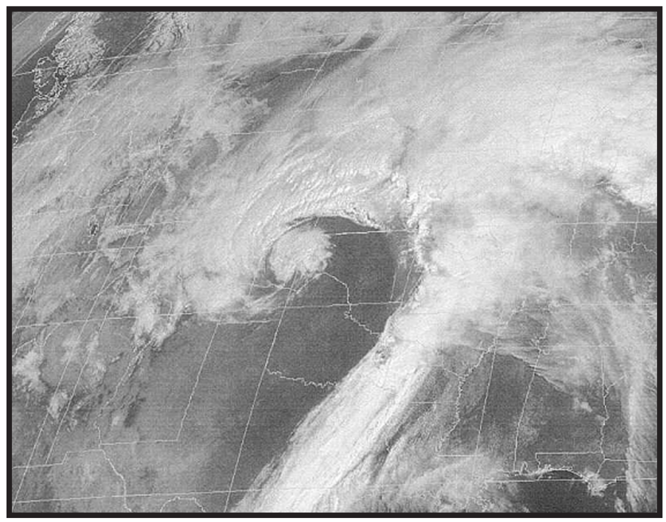

Figure 4-48. GOES E VIS, 1545Z/11 April 2001.

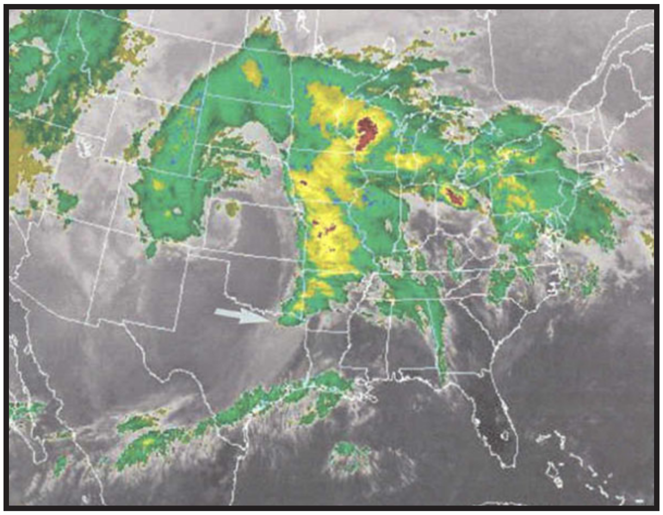

Figure 4-49. GOES E IR (Color-Enhanced), 1415Z/ 11 April 2001.

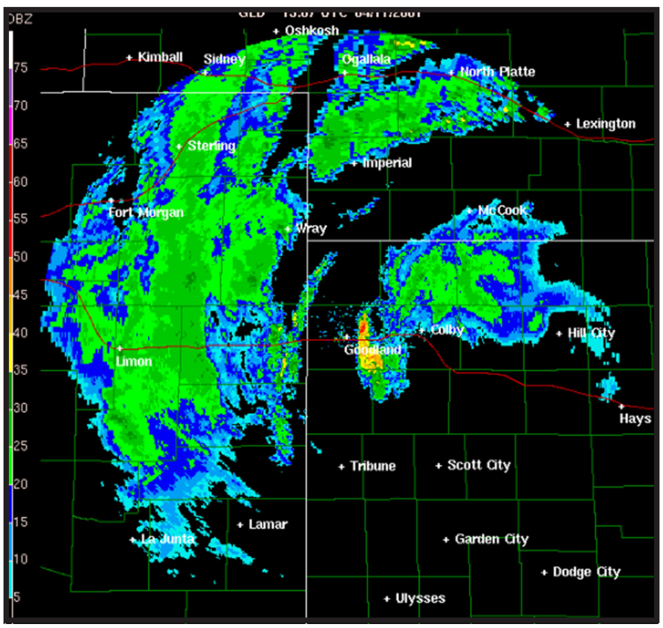

Figure 4-50. KGLD Doppler Radar, 1507Z/11 April 2001.

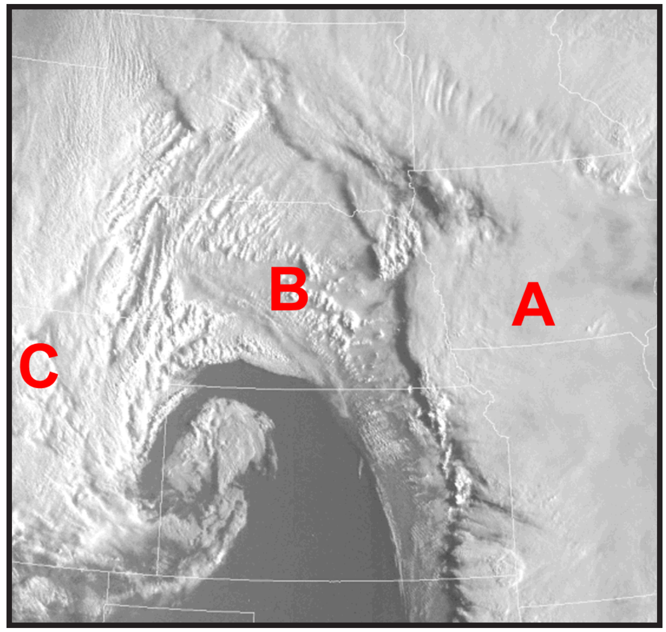

Figure 4-51. GOES E VIS, 1315Z/11 April 2001. Early morning photo reveals shadows that help define the primary cloud systems. The baroclinic cloud system is located over Missouri and Iowa (A) and the area of heaviest precipitation is shown at point C. The deformation zone is observed at B.

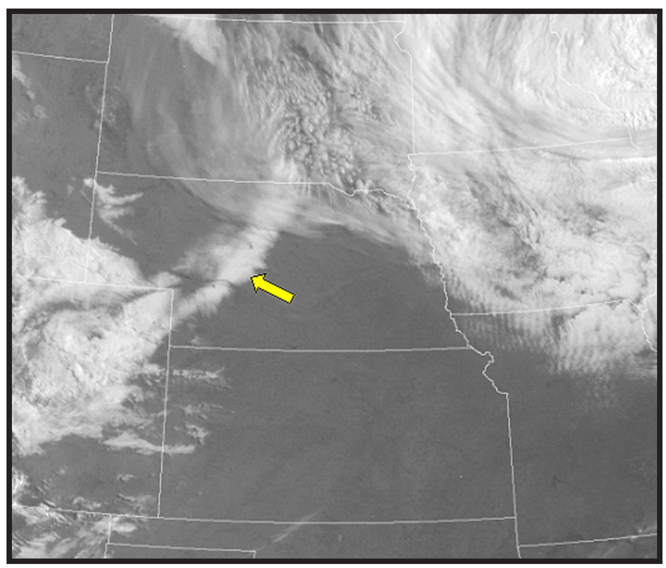

Figure 4-52. GOES E VIS, 1432Z/12 April 2001. The following morning visible photo reveals a narrow swath of snowfall over the western region of the upper Great Plains (noted by the arrow).

Example 2 – 22 April 2001

Another Colorado low example that occurred eleven days later is shown in Figures 4-53 through 4-62. Snow occurred from eastern Colorado and Wyoming northeastward across western Nebraska and South Dakota into Minnesota as will be shown in Figures 4-60 and 4-61.

The ETA 12-hour forecast places the 500mb low over northern Arizona – an ideal regime for significant snowfall over the higher elevations of Arizona and New Mexico (Figure 4-55).

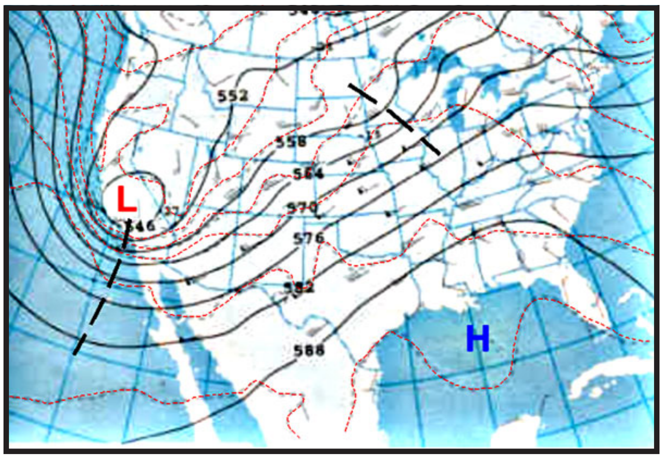

Figure 4-53. 500 mb, 1200Z/21 April 2001. Pacific short wave with a closed low has moved into the south-western CONUS region.

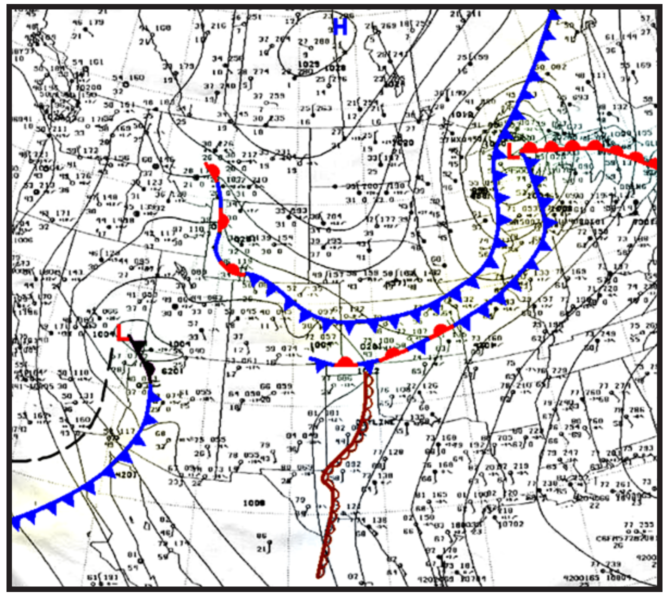

Figure 4-54. Surface, 1800Z/21 April 2001. The associated mP cold front is shown over the Great Basin and Arizona areas. Also, a cP ridge has moved into the central Plains and should provide sufficient cold air for snow potential.

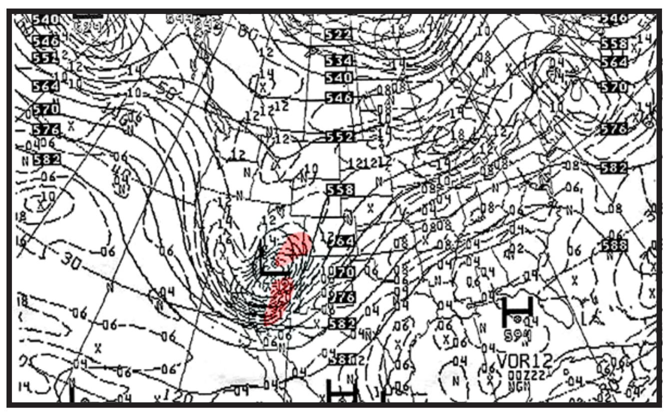

Figure 4-55. 12HR 500MB Heights/Vorticity, 0000Z/22 April 2001.

The 12-hour ETA surface forecast is depicted in Figure 4-56. The cold front is entering western Texas. The cP cold front has become stationary over Kansas and Missouri and overrunning of Gulf moisture has begun.

The 24-hour ETA forecasts were not captured, instead, the 500mb and surface analyses are shown for the next 12-hour period (Figures 4-57 and 4-58). In Figure 4-57, the 500mb low has begun to lift northeastward over northern New Mexico due to a strong ridge over the eastern CONUS. It is important for Great Plains forecasters to recognize when these short waves begin to recurve to the northeast using model guidance in order to forecast the track of snowfall. The empirical rule of height fall center track and its relationship to the path of snowfall is often useful (will be shown in Figures 4-60 through 4-62).

In Figure 4-58, the stationary Colorado low continues to deepen as it waits for its upper level support. Strong east-west surface gradient (and southerly low-level jet) over the southern Great Plains is bringing abundant moisture northward over the stationary front as shown in the Weather Depiction chart (Figure 4-59). The shaded areas in Figure 4-58 depict precipitation.

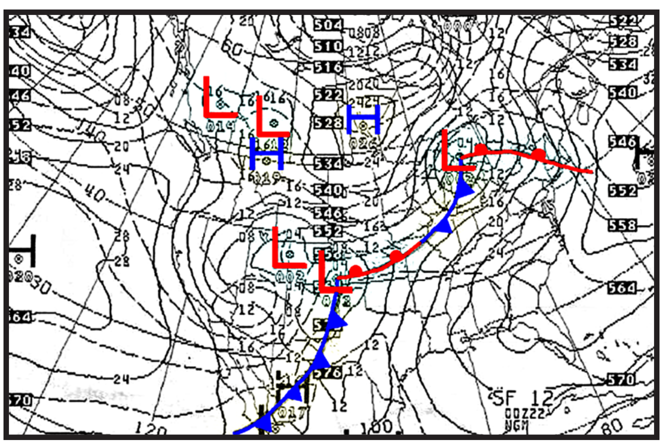

Figure 4-56. 12HR MSL PRES/1000-500MB THCKNS, 0000Z/22 April 2001. An ideal Colorado Low setup.

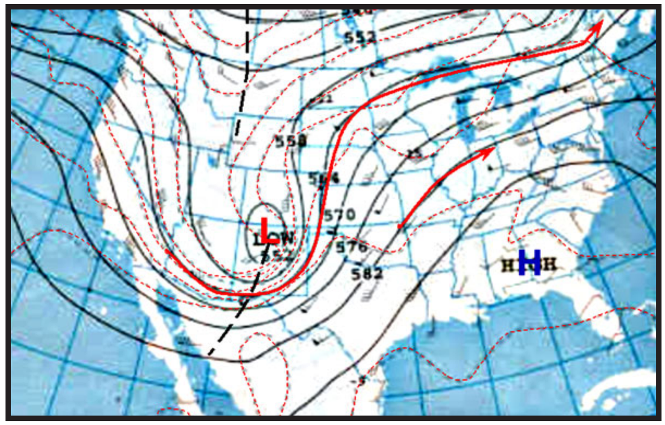

Figure 4-57. 500 mb, 1200Z/22 April 2001.

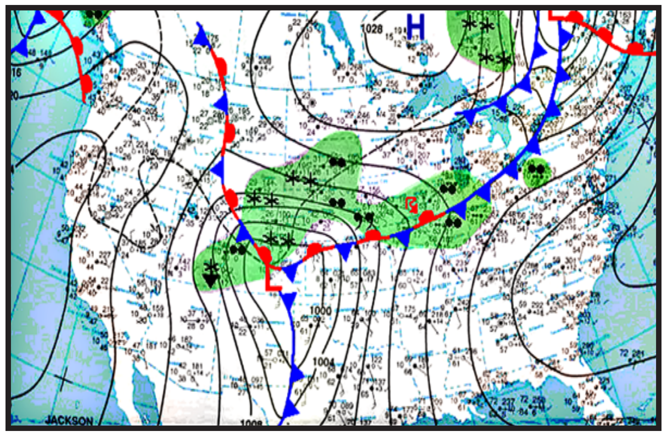

Figure 4-58. Surface, 1200Z/22 April 2001. Shaded area illustrates precipitation.

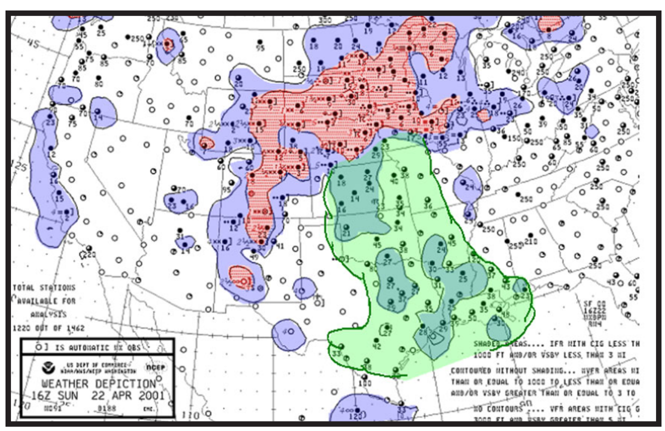

Figure 4-59. Weather Depiction, 1600Z/22 April 2001. Four hours later from Figure 4-58. Gulf moisture can be seen from eastern Texas northward to Kansas and Nebraska (outlined by the green scalloped lines).

Figures 4-60a through 4-60d illustrate the associated track of the height fall centers (HFCs) in 12-hour time periods. In Figure 4-60a, the center is shown just south of the Arizona border; the center was located over south central California 12 hours earlier (not shown). In Figure 4-60b, the center has lifted northeastward and is shown in the vicinity of Albuquerque, New Mexico. . Since the system has "bottomed out" one could project a straight line northeastward (with little eastward movement of the trough) over eastern Colorado to western Nebraska to determine the path of snowfall. Snowfall lies to the left of the HFC track (See Winter Regimes for more information).

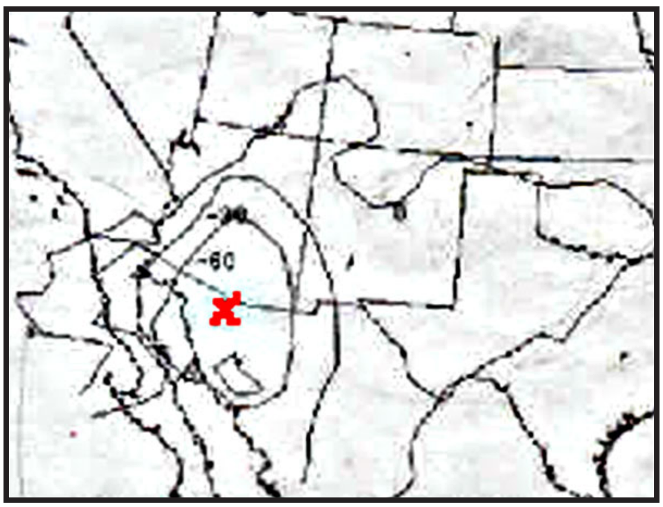

Figure 4-60a. 500 mb HFC, 21/1200Z to 22/0000Z April 2001.

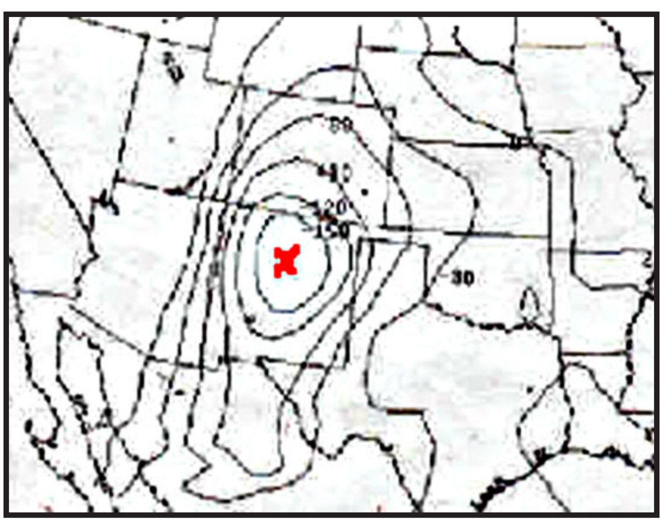

Figure 4-60b. 500 mb HFC, 22/0000Z to 22/1200Z April 2001.

The next 12 hours, Figure 4-60c, the storm system continues northeastward and the HFC is located over southwestern Nebraska. Further northeastward movement of the system during the next twelve hours is shown in Figure 4-60d. The HFC is located over southwestern Minnesota.

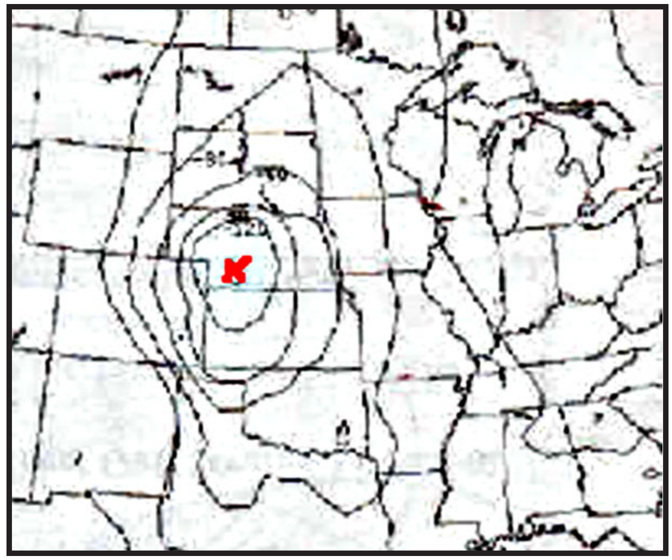

Figure 4-60c. 500 mb HFC, 22/1200Z to 23/0000Z April 2001.

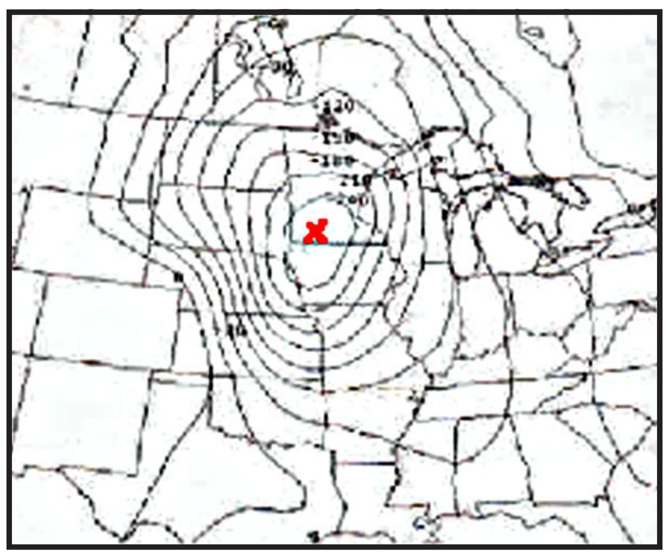

Figure 4-60d. 500 mb HFC, 23/0000Z to 23/1200Z April 2001.

The visible satellite images, Figures 4-61 and 4-62, illustrate the ensuing snow swath with this storm. In Figure 4-61 the HFC track is indicated by the dashed track with the 12-hour center locations marked by an X. Figure 4-62 shows a close-up of the snow swath.

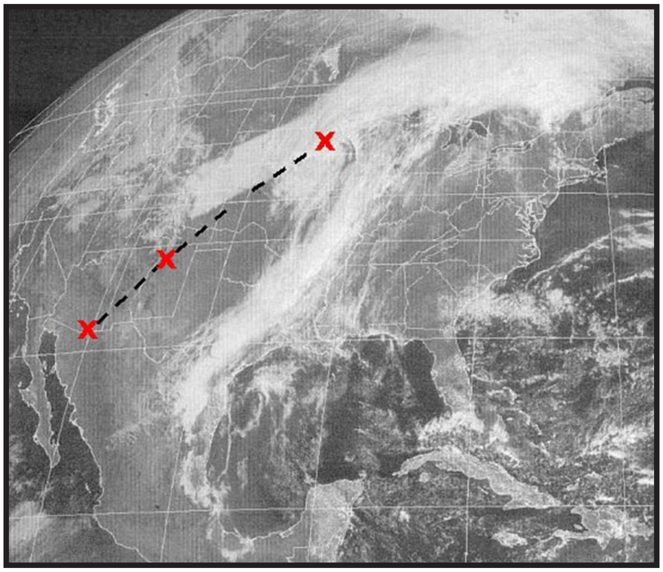

Figure 4-61. GOES E VIS, 1432Z/23 April 2001

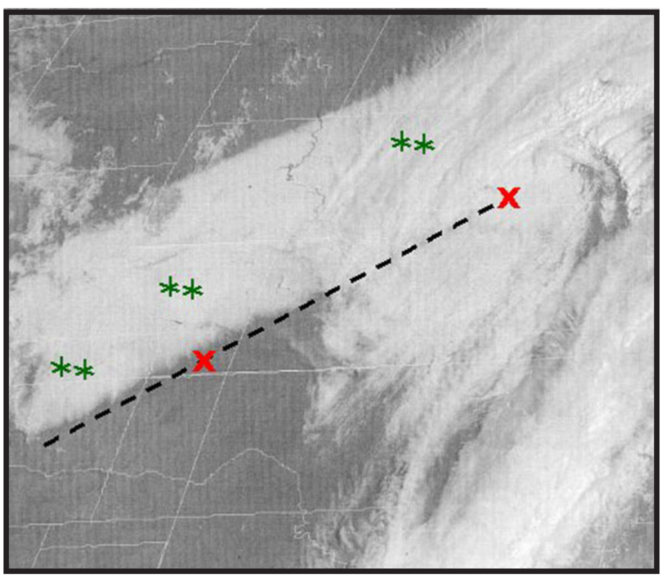

Figure 4-62. GOES E VIS, 1432Z/23 April 2001

Figures 4-63and 4-64 depict the storm as it moves northeastward across the central CONUS.

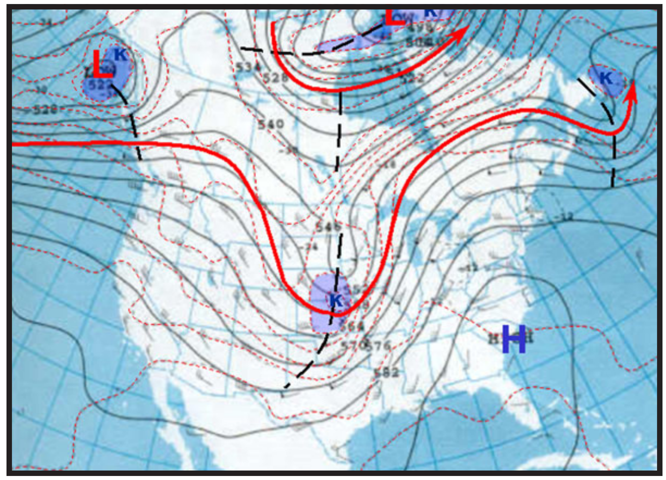

Figure 4-63. 500 mb, 1200Z/23 April 2001. Short wave is shown over the central CONUS.

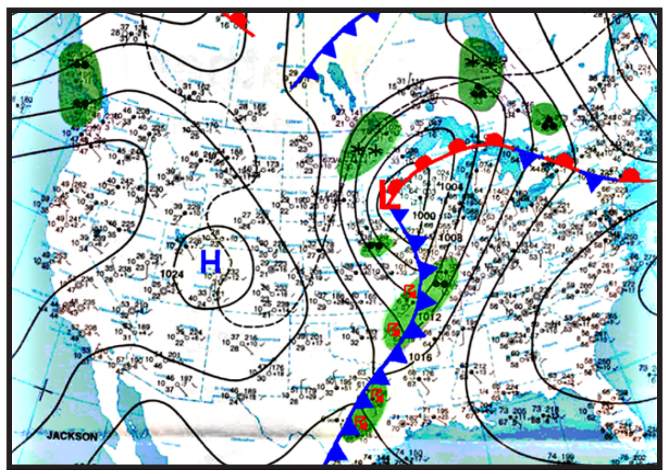

Figure 4-64. Surface, 1200Z 23 April 2001

Example 3 – 6-7 April 2001

Figure 4-65 (4-65a through 4-65f) illustrates water vapor images of Colorado Low development from its birth to the occluded stage over an 18-hour period. As seen in this series of images, springtime Colorado Lows can develop rapidly and may deposit a swath of snow across the eastern regions of Colorado, Wyoming and Montana and the western areas of Nebraska, South Dakota and North Dakota.

Example 4 – 27 April 1984

The threat of a Rocky Mountain major snowstorm over the central Great Plains may continue through the end of March and into early April. The threat continues over the northern Great Plains and eastward to the Great Lakes region into late April as shown by the following examples in Figure 4-66 through Figure 4-68.

Figure 4-65a. 2115Z/6 April 2001.

Figure 4-65b. 0115Z/7 April 2001.

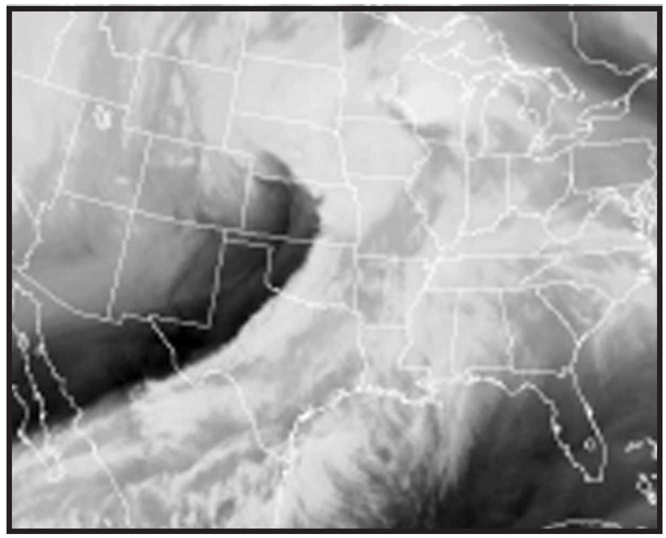

Figure 4-65c. 0315Z/7 April 2001.

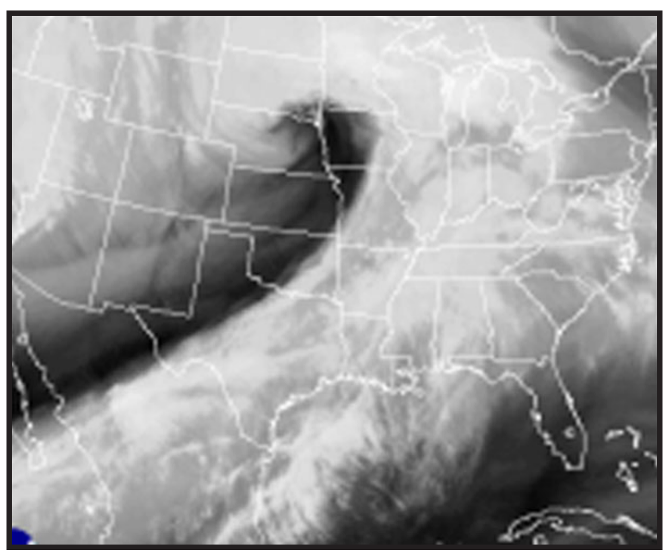

Figure 4-65d. 0715Z/7 April 2001.

Figure 4-65e. 1215Z/7 April 2001.

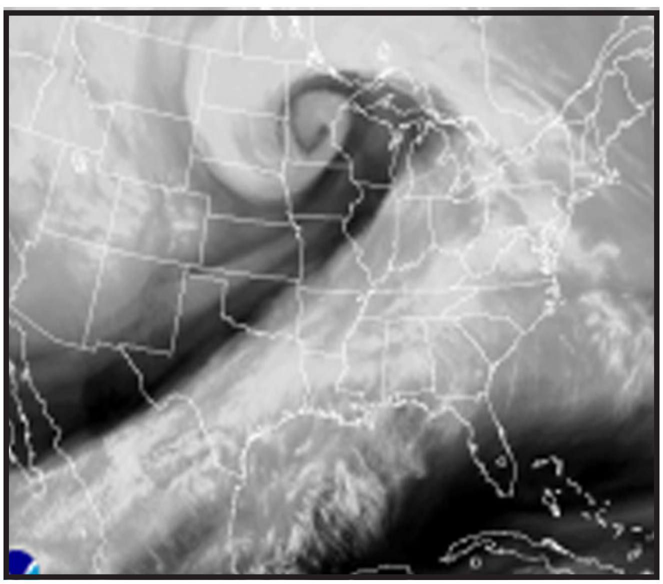

Figure 4-65f. 1515Z/7 April 2001.

Example 5 – 19 March 1984

Figure 4-67 depicts a mid March event that deposited heavy snow from Kansas northeastward across Nebraska and Iowa into Minnesota and Wisconsin. This storm developed over the southern Rocky Mountains as noted by the red/white dashed line. The intent in adding this event a few days prior to the official onset of spring is that significant snowfall can occur over the central Great Plains region through late March and early April when strong Colorado or New Mexico lows track eastward as shown in Figure 4-67.

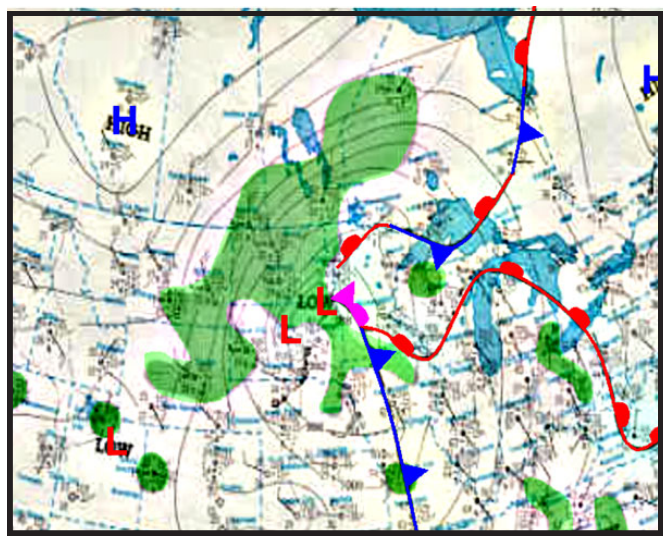

Figure 4-66. Surface, 1200Z/27 April 1984. Snow is occurring over eastern Montana and Wyoming and North Dakota.

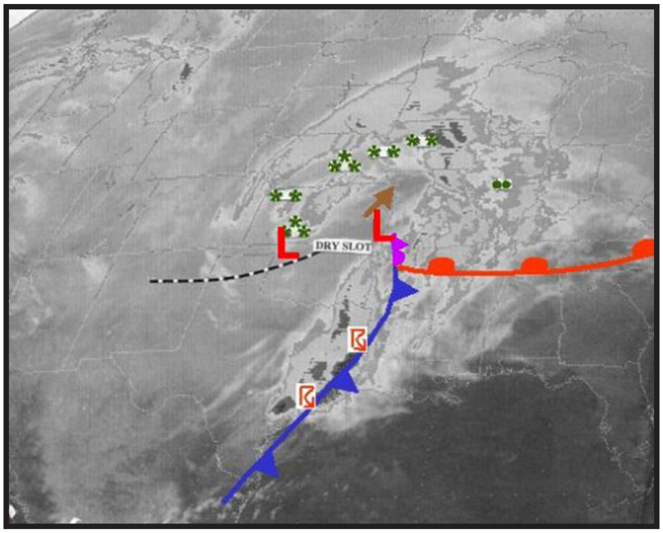

Figure 4-67. GOES E IR, 1201Z/19 March 1984. Significant snowfall has occurred in northern and western areas of the large comma.

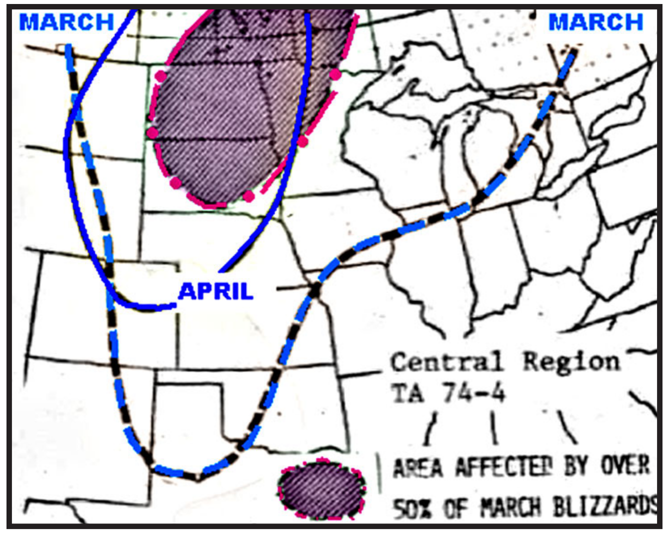

Figure 4-68. Areas Affected by Blizzards During March and April.

Areas Affected by Spring Blizzards

Figure 4-68 depicts locations that may be affected by spring blizzards in March and April. In April, the potential threat area shifts westward over the western Great Plains and eastern Colorado and Wyoming region and is most likely due to Colorado Low development as shown in the previous examples.

Great Plains Cyclogenesis

Discussions so far addressed cyclogenesis regimes along and east of the Rocky Mountains. It was shown earlier in this Chapter that frontal systems often become stationary east of the Rocky Mountains as the polar jet shifts northward. The threat for heavy snowfall events over the central Great Plains and eastward into the Great Lakes region are likely to continue through the remainder of March and ending in mid-April. Significant snowfall events over the northern Great Plains are likely through April.

Example 1 – 24 March 2002

Figures 4-69 through 4-73 depict an early spring snowstorm that occurred over the central plains. In Figure 4-69, a strong cP outbreak advanced southward into the central Great Plains. The weather depiction chart, Figure 4-70, illustrates the cloud systems with this developing storm.

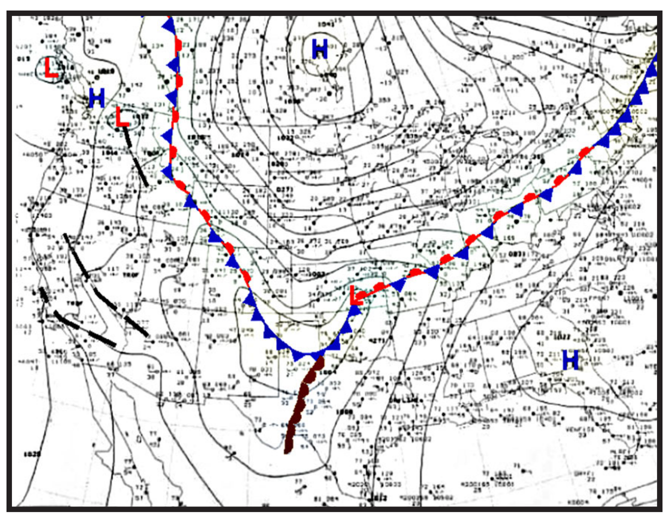

Figure 4-69. Surface, 1800Z/24 March 2002.

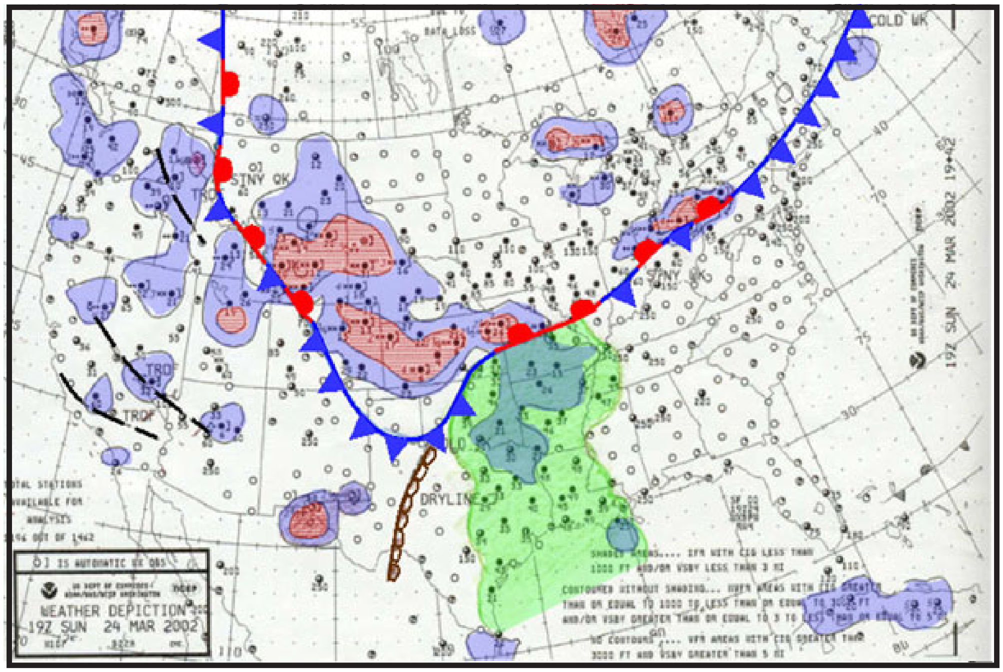

Figure 4-70. Weather Depiction, 1900Z/24 March 2002. Extensive overrunning north of the polar front. Gulf stratus advection (green shaded area), will provide further moisture as it overruns the polar front.

The GOES visible satellite image, Figure 4-71 clearly identifies the two primary cloud systems. An elongated east-to-west overrunning cloud band stretches from the East Coast to the Rocky Mountains. Gulf moisture advection is shown from the Texas/Louisiana area to the polar front over Missouri and Illinois.

The ETA surface and 500mb 12-hour forecasts are respectively shown in Figures 4-72 and 4-73. In Figure 4-72, a frontal low is forecast over Oklahoma – waiting for its upper support shown by the closed low over western Kansas in Figure 4-73.

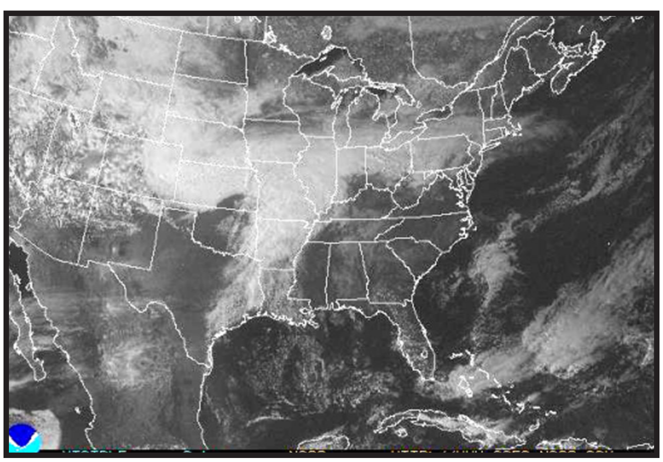

Figure 4-71. GOES E VIS, 2115Z/24 March 2002.

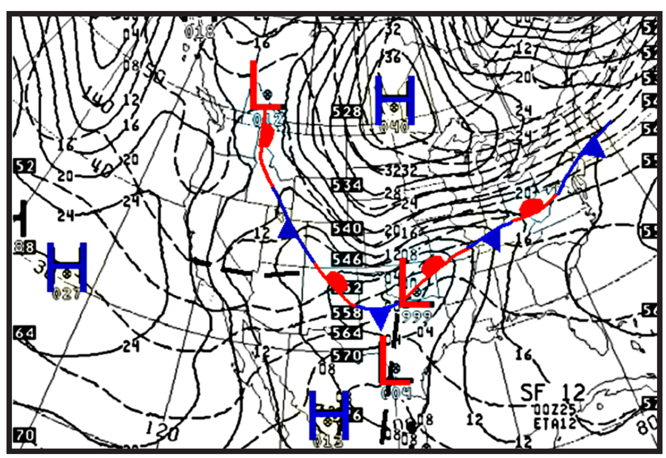

Figure 4-72. ETA 12HR MSL PRES/1000-500MB THCKNS, 0000Z/25 March 2002.

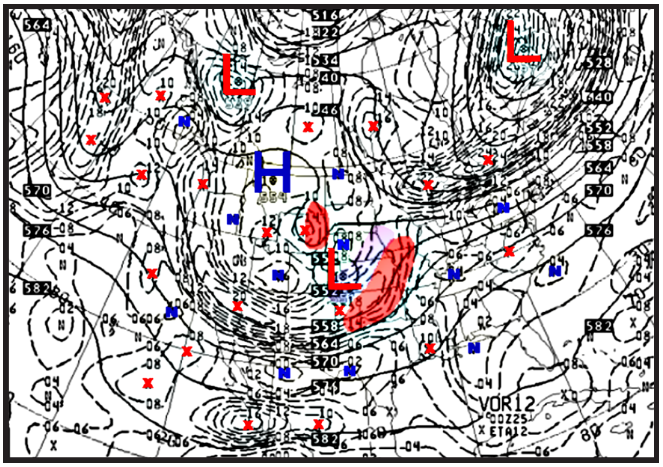

Figure 4-73. ETA 12HR 500 HEIGHTS/ VORTICITY, 0000Z/25 March 2002.

Figure 4- 74 depicts the new snowfall from western Nebraska and northwest Kansas to the Great Lakes region.

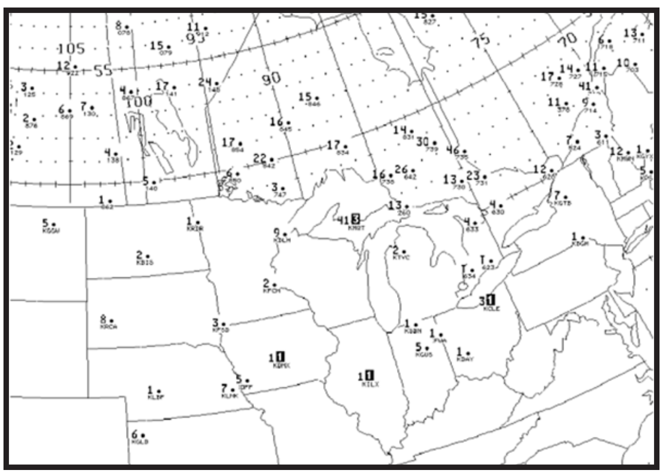

Figure 4-74. Observed Snow Cover, 1200Z/25 March 2002.

Example 2 – 20-21 April 1972

A more common scenario over the Great Plains during mid and late spring involves east-to-west oriented cP cold fronts that have reached their southern limits because associated anticyclones track further northward as exemplified in a mid-April event shown in Figure 4-75. By the onset of summer, stationary fronts are likely to occur across the northern CONUS as low pressure systems, associated with the prevailing westerlies, move across central and northern Canada.

Figure 4-76 shows the related 500-mb analysis. The upper air pattern is similar to the Colorado Low, where Pacific short waves (and upper lows) are approaching the Great Plains. In these cases, primary frontal cyclogenesis occurs along existing east-west stationary fronts rather than mP frontal systems oriented north-south along the Rockies.

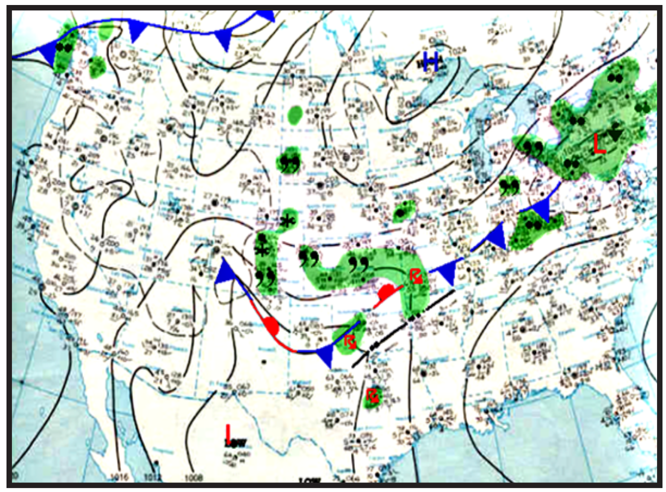

Figure 4-75. Surface, 1200Z/20 April 1972.

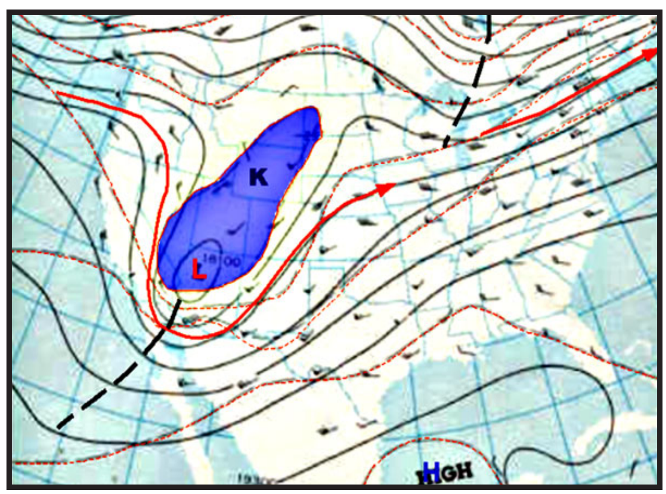

Figure 4-76. 500 mb, 1200Z/20 April 1972.

Figures 4-77 and 4-78 show the low-pressure system over the central Great Plains that developed along the stationary front discussed in Figure 4-75. In Figure 4-77, cold frontal thunderstorms occurred from central Missouri to eastern Texas.

The short wave, located over the southwestern CONUS 24 hours before (Figure 4-76), has rounded the base of the longwave trough over the southern Rockies, and lifted northeastward into the northern plains as shown in Figure 4-78.

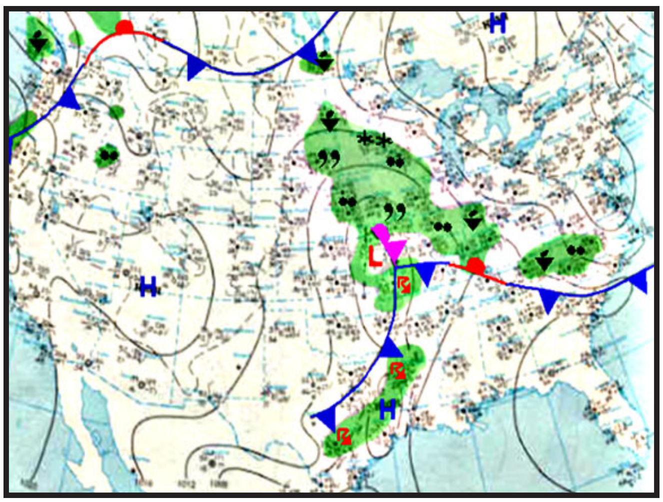

Figure 4-77. Surface, 1200Z/21 April 1972. Surface low formed along the stationary front in northern Oklahoma 12 hours earlier.

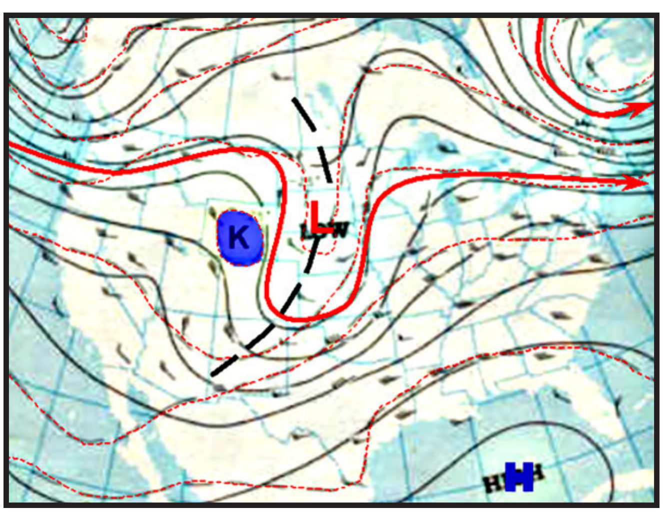

Figure 4-78. 500 mb, 1200Z/21 April 1972.

Example 3 – 4-5 May 2001

Another example is shown in Figures 4-79 through 4-84. In Figure 4-79, a short wave appears over the Great Basin region. A ridge over the eastern CONUS will likely force the short wave to track northeastward when it enters the western Great Plains.

In Figure 4-80, a stationary front lies across the Great Lakes to the central plains. No further southerly movement of the cold front over the eastern CONUS is likely due to upper-level ridging over that area. Frontal wave cyclogenesis appears to be taking place over western Texas as the upper system approaches.

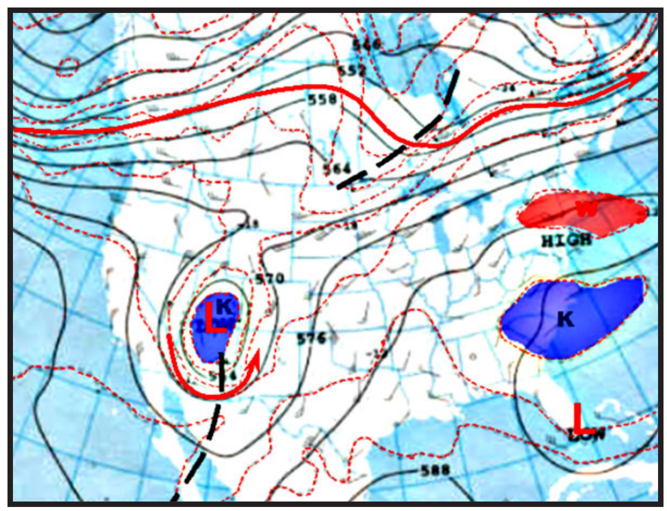

Figure 4-79. 500 mb, 1200Z/4 May 2001.

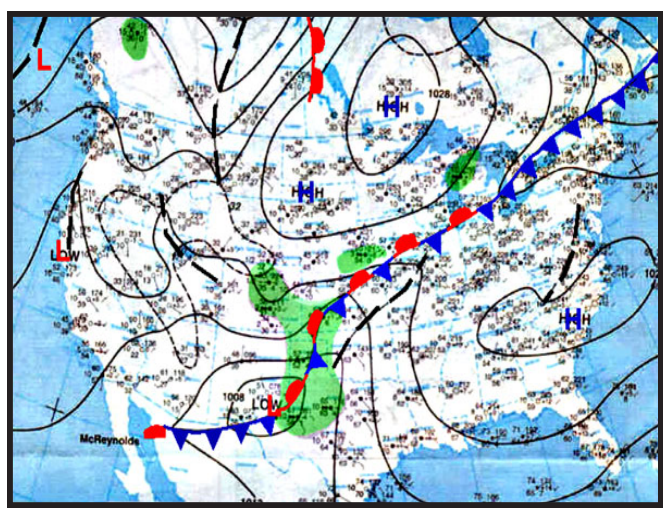

Figure 4-80. Surface, 1200Z/4 May 2001.

Figures 4-81 and 4-82 depict the developing low twenty-four hours later. In Figure 4-81, a strong ridge continues over the eastern CONUS, which will likely force the Central Rockies Low northward.

Figure 4-82 shows the developing low system over the central Great Plains. It has moved northward as expected. Snow is occurring over eastern Colorado, which is not uncommon during May.

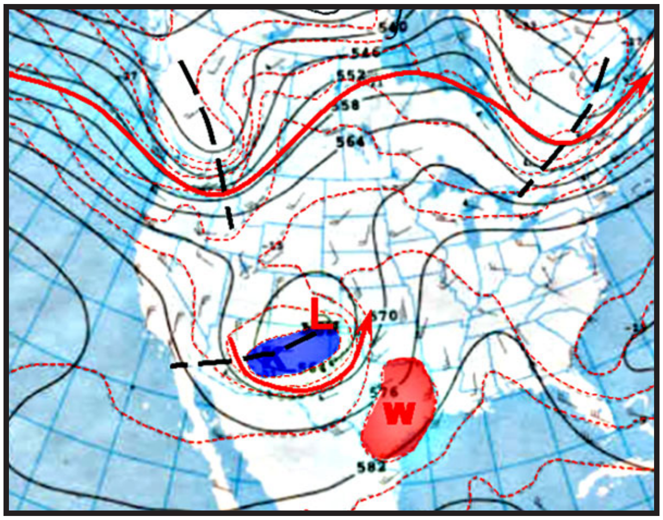

Figure 4-81. 500 mb, 1200Z/5 May 2001

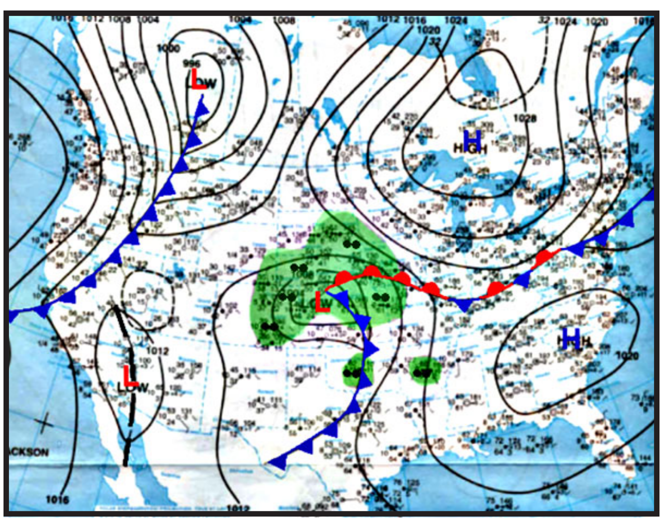

Figure 4-82. Surface, 1200Z/5 May 2001

Figure 4-83 shows a visible image approximately three hours later from Figure 4-82. The heavy precipitation region lies over Colorado and southeast Wyoming. Significant snowfall is occurring over parts of Colorado and Wyoming.

Later in the afternoon, Figure 4-84, the storm system has continued northward. Cold frontal thunderstorms have increased over central and eastern Texas, Oklahoma and Kansas. Thirty-two severe reports were reported between 04/0000Z and 06/0000Z over Texas, Oklahoma, and Kansas.

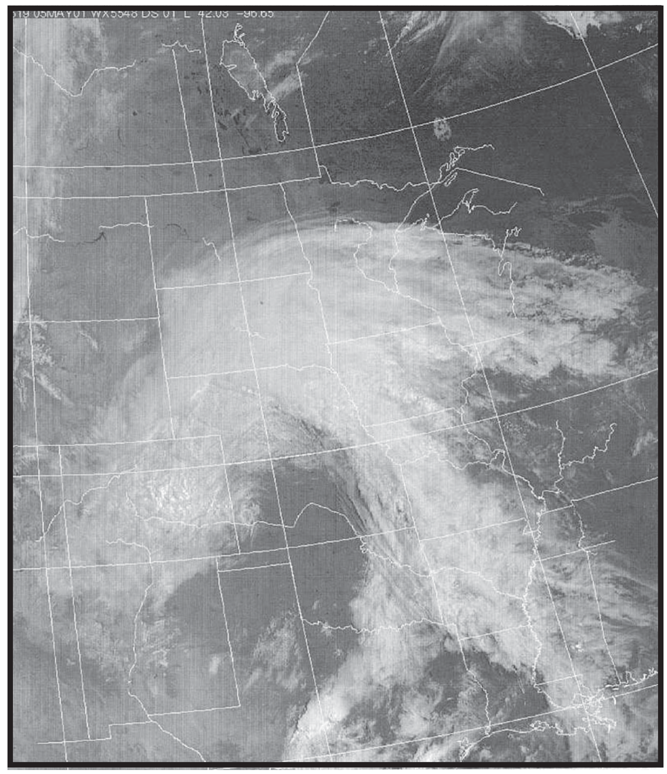

Figure 4-83. GOES E VIS, 1519Z/5 May 2001. Cold frontal thunderstorms are developing over western Texas.

With the onset of the summer's subtropical ridge regime over the southern and central CONUS (and a continued northward shift of the westerlies and associated jet streams), frontal systems seldom move into the southern CONUS. Conversely, cold fronts would push into the Deep South when upper-level northwest flow is established over the central plains. Figure 4-85 illustrates a late spring surface analysis – a typical pattern for most of the summer where a majority of the central and southern CONUS is under a moist and unstable southerly air mass.

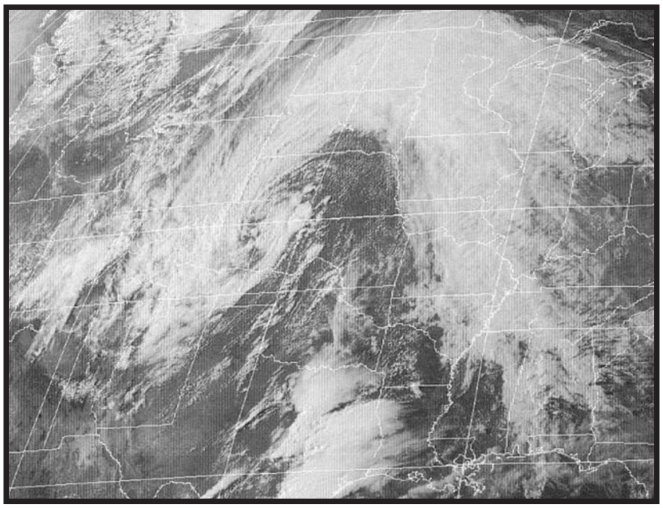

Figure 4-84. GOES EAST VIS, 2245Z/5 May 2001.

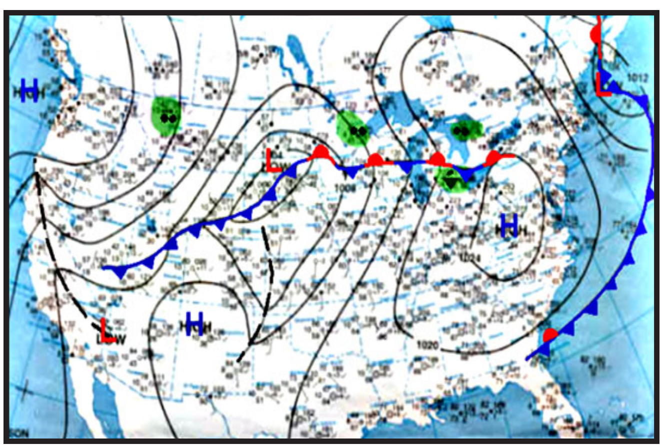

Figure 4-85. Surface, 1200Z/18 June 2001

Cutoff Lows

Cutoff low events were presented earlier in Chapter 2 (Figure 2-14 and 2-15). They occur often in May and June and may remain stationary over a given area for several days. Moderate-to-heavy rainfall is often associated with these stationary systems. The following three NGM 500-mb forecasts show how the low breaks away from the short wave trough to the north. In Figure 4-86, a 12-hour forecast, the main short wave is depicted over the Great Lakes. A separation between the Great Lakes trough and the low over the southern Great Plains suggest the Oklahoma low will cut off and lag behind.

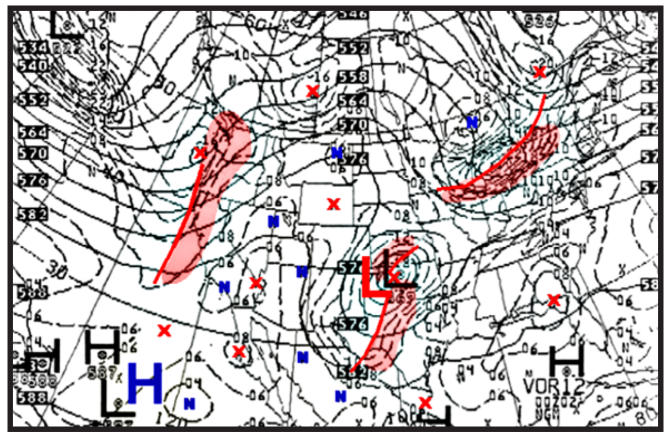

Figure 4-86. 12HR 500MB HEIGHTS/ VORTICITY, 0000Z/02 May 2000.

The next 12-hour forecast, Figure 4-87, shows that the Great Lakes short wave continues eastward across the New England region. The low has definitely cut off from the main westerly flow, as depicted in Figures 4-87 and 4-88. In this particular event, forecasters over the southern and central Great Plains should expect persistent weather conditions over their area for several days. Daily thunderstorms are likely.

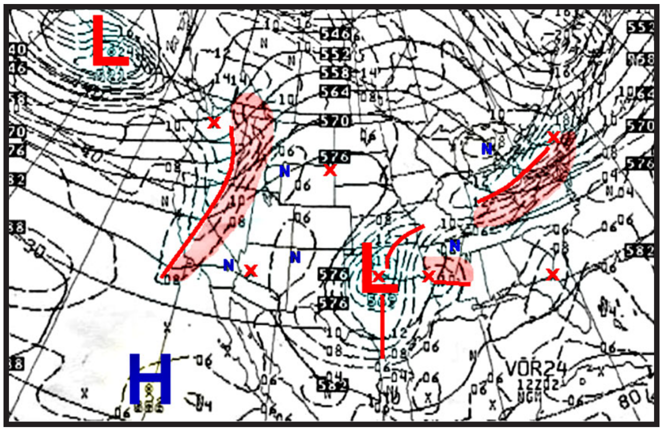

Figure 4-87. 24HR 500MB HEIGHTS/ VORTICITY, 1200Z/2 May 2000.

Low-Level Jet and Gulf Moisture Advection

Increased low-level jet activity is expected across the southern Great Plains – lower Mississippi Valley area northward into the central CONUS. There will be more maritime polar cold fronts crossing the Rocky Mountains into the Great Plains that establish a warm advection east-west pressure gradient east of the Rockies. During the spring season, nocturnal low-level jets develop often within this gradient. Low-level jets are likely to be more intense than any other time of the year. 50-60 knot jet maxima are not uncommon and 60-80 knots have been reported during March.

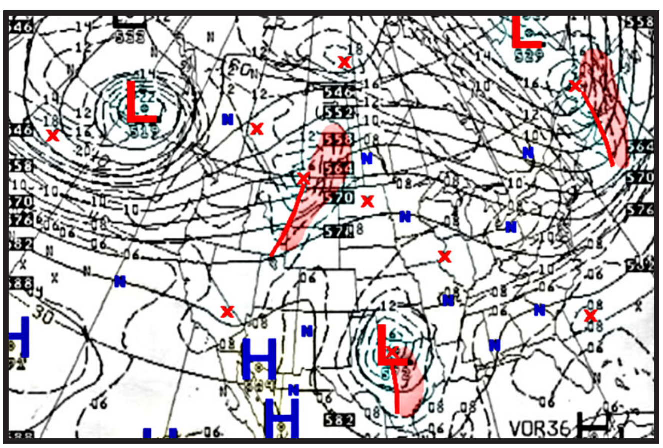

Figure 4-88. 36HR 500MB HEIGHTS/ VORTICITY, 0000Z/03 May 2000.

As a result of increased low-level jet activity, there will be more intrusions of moisture from the Gulf of Mexico and southern Texas. These tongues of moisture, in the form of stratus generally below 1500m, often reach as far north as Nebraska and Iowa ahead of approaching mP cold fronts as shown in the model example, Figure 4-89. Figure 4-89 also illustrates an example of stratus advection. *Note: see Winter Regimes for a more detailed discussion on the relationship of low-level jet and Gulf moisture advection.*

Gulf Stratus Advection Tracks

Stratus enters Texas from the Gulf of Mexico along various tracks, but for practical use, three main tracks have been identified.

- **Type 1** – Formation is in eastern Mexico (east of the mountains) with stratus advection into western Texas and northward.

- **Type 2** – Stratus advects inland along the Texas Gulf Coast and spreads northward.

- **Type 3** – Development over south central Texas with rapid advection into the Central Plains.

Only Type 2 will be presented in this Technical Note. (Types 1 and 3 occur during the winter season - see *Winter Regimes* for further information regarding Types 1 and 3). Type 2 stratus advection continues through mid-spring.

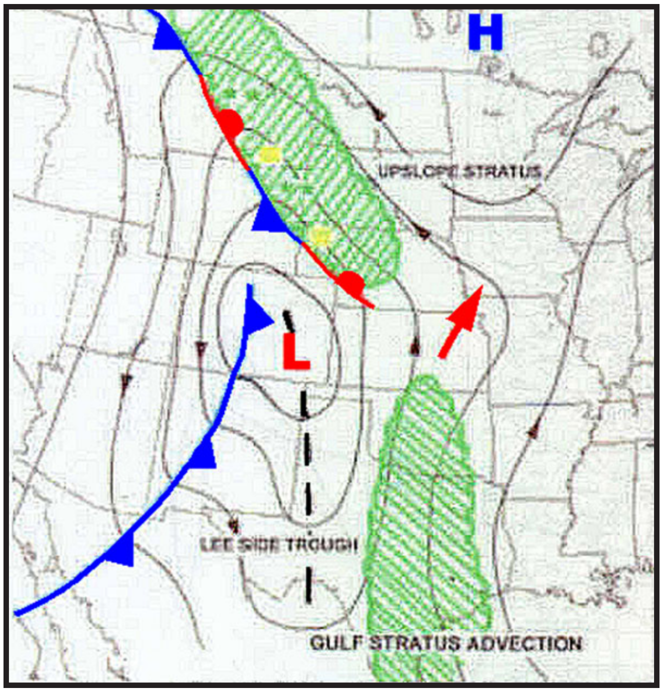

Figure 4-89. Gulf Stratus Advection Model.

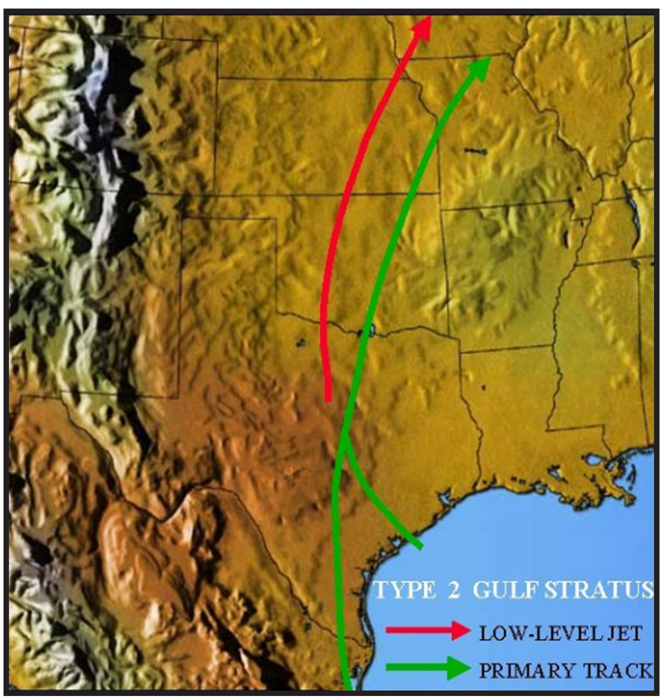

Figure 4-90. Type 2, Gulf Stratus Advection Track and LLJ Position.

Type 2 Gulf Stratus

When an extensive surface anticyclone moves into the northeastern CONUS, strong southeasterly flow is established within the low levels through the Gulf. The first evidence of this type advection can occur anywhere along the Texas coast, depending on where the low-level moist flow is located. Two main tracks are shown in Figure 4-90 over southern Texas. Initial reports from the coastal stations can begin at any time. Ceilings are generally at 2,500 feet with tops at 5,000 feet during the first few hours. Type 2: Gulf stratus advects reliably into the Central Plains and is always thick enough to preclude dissipation. Figures 4-91 through 4-93 depict Type 2 stratus events.

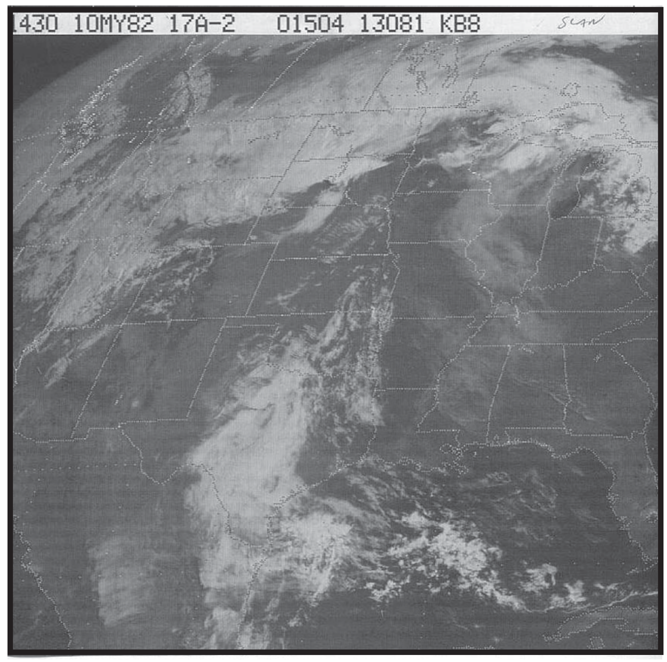

Figure 4-91. GOES E VIS, 1430Z/10 May 1982. Gulf stratus advection over the southern Plains.

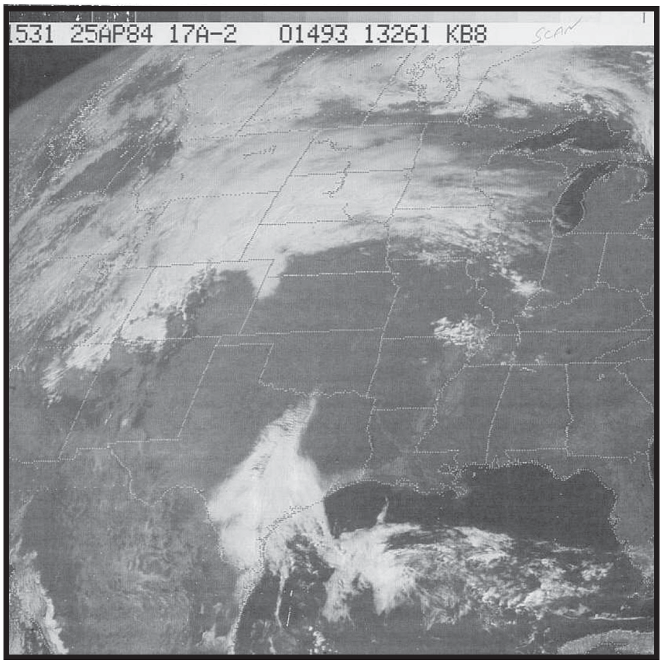

Figure 4-92. GOES E VIS, 1531Z/25 April 1984.

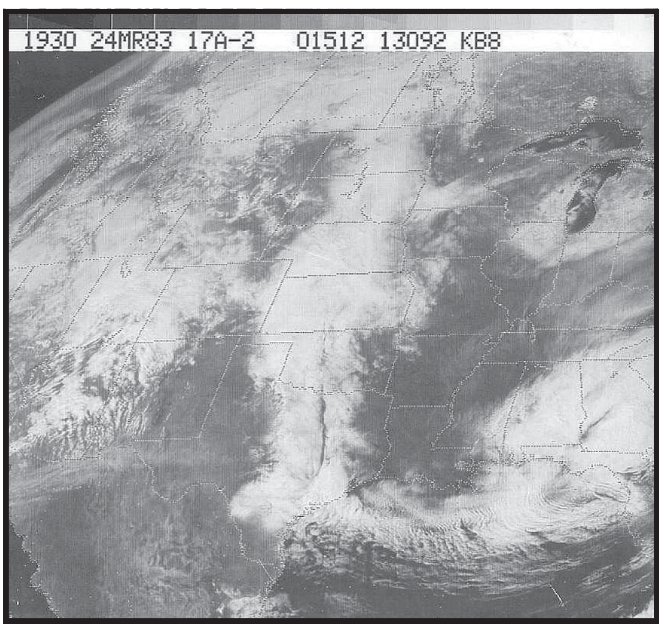

Figure 4-93. GOES E VIS, 1930Z/24 March 1983 Type 2. Gulf moisture has spread northward to North Dakota.

Low-Level Jet

Figure 4-94 shows a typical synoptic setup for stratus advection. Southerly low-level jets develop east of the lee-side trough. Normally, a maritime polar cold front is approaching from the west and will "drop" into the lee-side trough (see Figure 4-89). Gulf stratus usually encounters the frontal system over central Oklahoma and Kansas.

Figure 4-95 is a vertical wind profile of low-level jet activity over the Oklahoma City region (OKC sounding) of a few years ago. The wind speed increased from 30 knots to 60 knots at 4,000 feet between 0000Z and 1200Z. In the 1200Z vertical wind profile, the slight decrease in wind speed at 7,000 feet probably is the defining layer between the top of the low-level jet and the bottom of the mid-level jet. Vertical wind profiles can also be routinely obtained from the WSR-88D Doppler radar vertical wind profile (VWP) product and wind profilers that are in place across the Great Plains.

Forecasting the strength of the low-level jet maximum wind speeds is difficult using analysis data. Numerical model forecast products are helpful. An empirical method for forecasting the maximum strength of the nocturnal low-level jet was developed from four years of data over the central and southern Great Plains many years ago. Figure 4-96 gives the relationship of the 0000Z Amarillo (AMA) and Fort Worth - Dallas (FWD) 850 mb gradient and the forecast 0600Z low-level maximum winds over Oklahoma City (OKC) which would be representative all along the jet stream corridor. The method is usable within a south-to-north flow (where no frontal/trough intrusions disrupt the gradient).

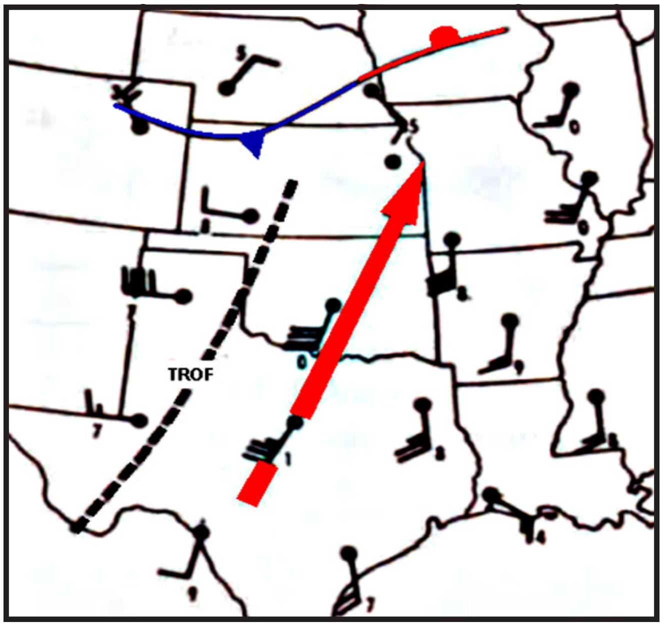

Figure 4-94. Low-Level Jet Formation Model.

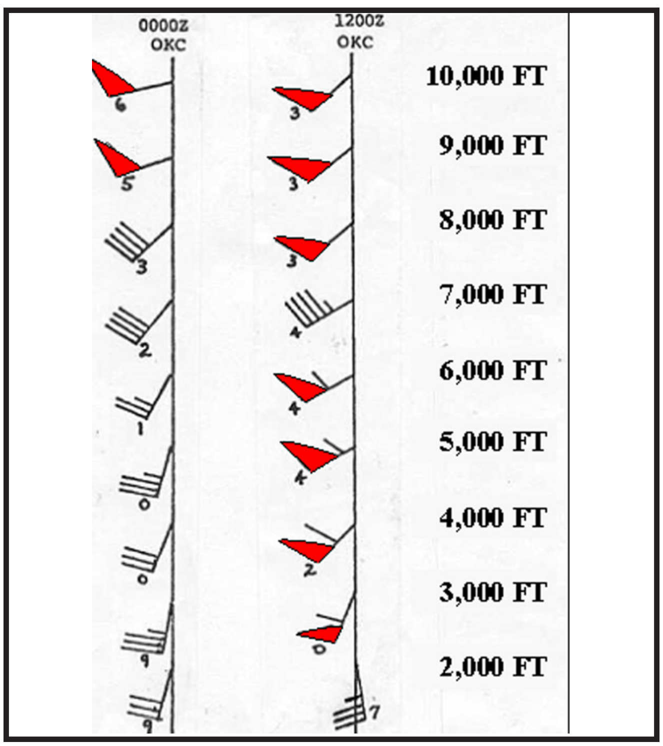

Figure 4-95. Wind Profile from Oklahoma City RAOB, Early March.

850 MB

GRADIENT/SPEED RELATIONSHIP

AMA - FWD

Initial 0000Z	Fcst 0600Z
DM (METERS)	JET SPEEDS
40 - 60	30 - 40K
60 - 75	40 – 50K
75 - 90	50 – 60K
≥ 90	> 60

Figure 4-96. 850mb Gradient/Speed Relationship.

Figures 4-97a through 4-97d depict an ideal pattern for Gulf stratus advection (drawn from case studies in the 1960s). The low-level jet appeared over western Kansas at 0600Z (Figure 4-97a) and shifted eastward and strengthened considerably at 1800Z (Figure 4-97c). Normally, the jet would not be this strong at 1800Z (60-70 knots), but probably persisted due to the strong pressure gradient (AMA-FWD 850-mb 100 meter gradient) at 1200Z (Figure 4-97b). The AMA - FWD 850-mb gradient decreased to 76 meters by 0000Z (Figure 4-97d). The hatched area shown in the figures represents Gulf moisture advection (Gulf stratus with ≤5,000 foot ceiling) at the valid time of the chart.

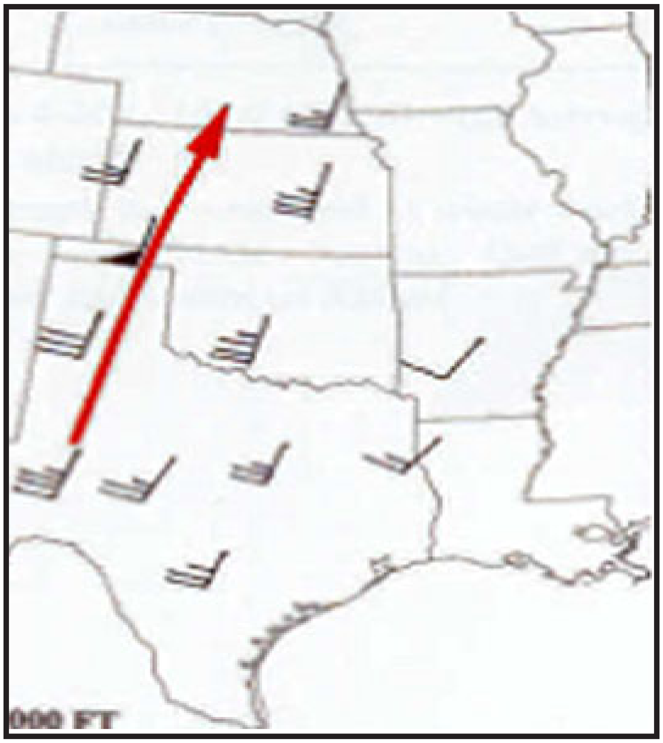

Figure 4-97a. Ideal Gulf Stratus Advection Case - 0600Z. Low-level jet has developed over the Western Plains

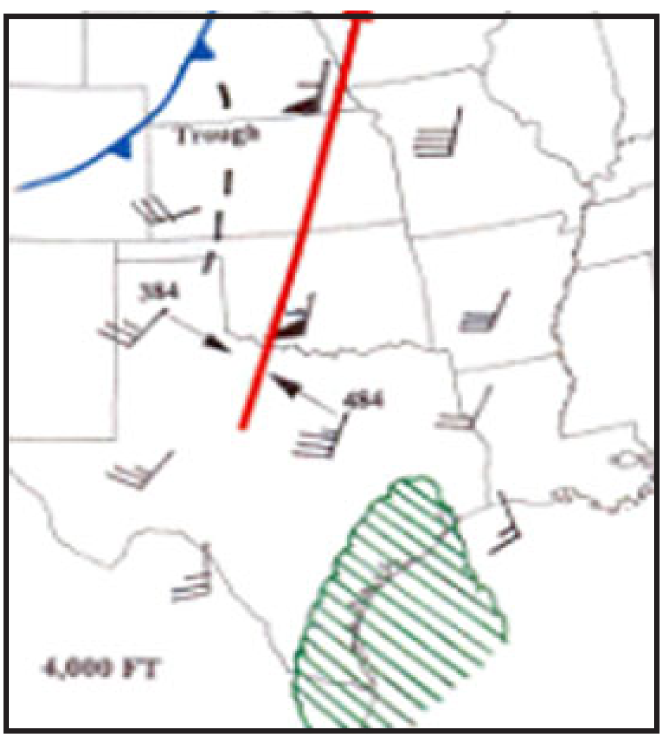

Figure 4-97b. Ideal Gulf Stratus Advection Case - 1200Z. Wind speeds increased as the LLJ shifts eastward. Gulf moisture has arrived.

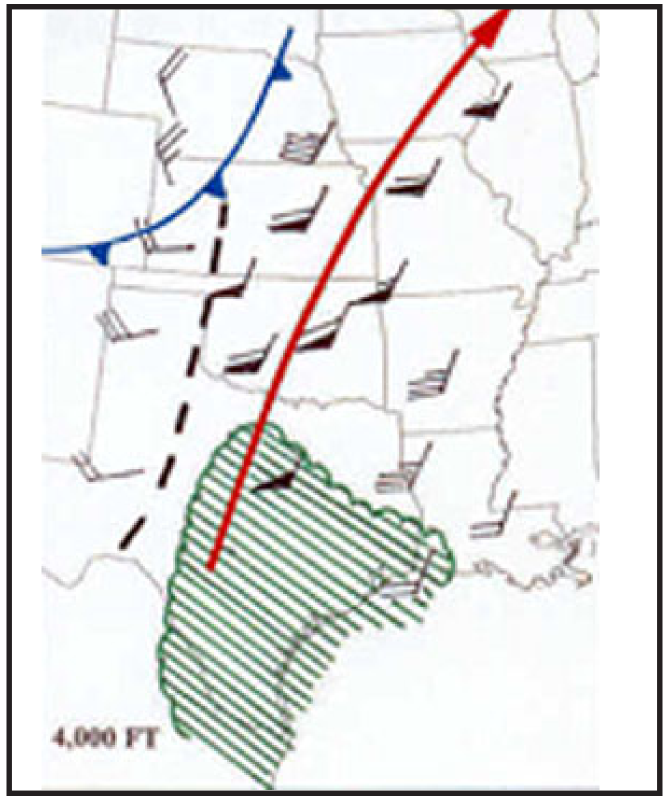

Figure 4-97c. Ideal Gulf Stratus Advection Case – 1800Z. Strong low-level jet across the Central Plains. Gulf moisture has advected into northern Texas.

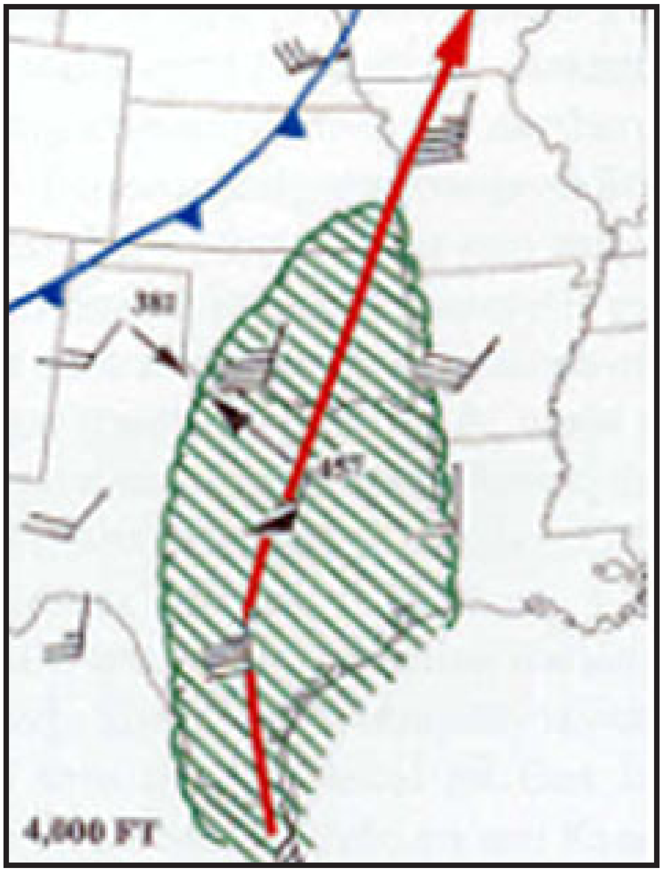

Figure 4-97d. Ideal Gulf Stratus Advection Case –0000Z. Jet strength has weakened as winds worked to the surface due to surface heating. Gulf moisture has advected into southeast Kansas. (Type 2 Gulf Stratus).

Low-Level Jet and Gulf Moisture Advection – 22 May 2002

A strong low-level jet and associated gulf moisture advection that affected the Great Plains from Texas northward to North Dakota and Minnesota occurred on May 22, 2002. Selected illustrations, Figures 4-98 through 4-104, depict this event. Included are satellite, RAOBS and wind profiler data. Figures 4-98 and 4-100 show morning soundings for Topeka, Kansas and Norman, Oklahoma. The adjacent satellite photos show gulf moisture advection approximately five hours later (Type 2 Gulf Stratus). In Figures 4-98 and 4-100 a strong low-level jet of ≥50 knots is below the inversion layer. Northward stratus advection was rapid as strong low-level winds carried the moisture northward, as depicted in Figures 4-99 and 4-101.

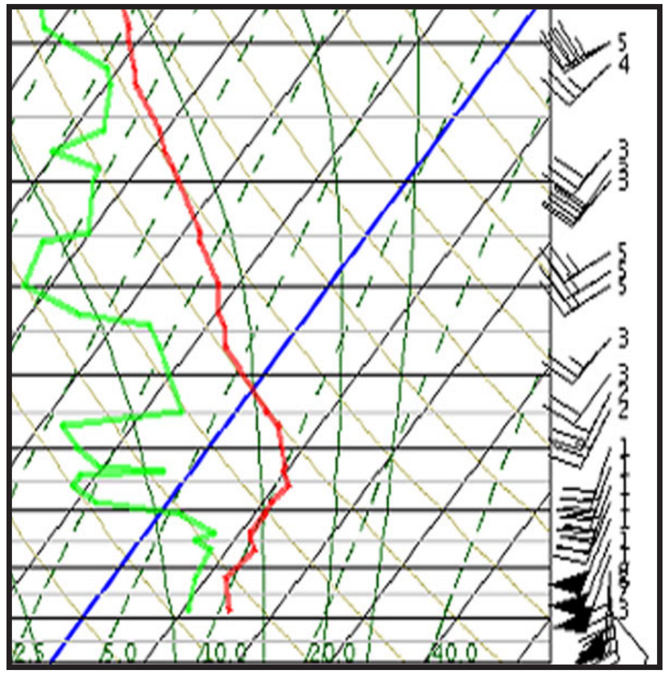

Figure 4-98. KTOP Topeka, KS (RAOB), 1200Z 22 May 2002.

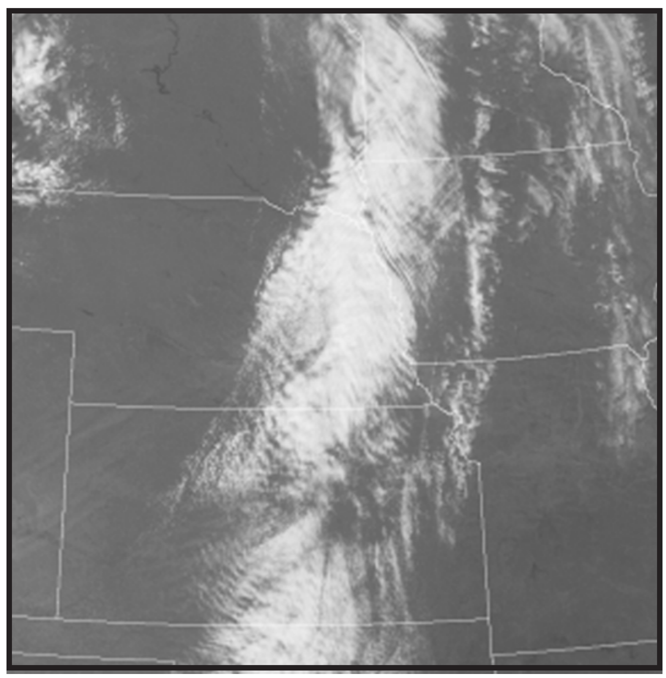

Figure 4-99. GOES E VIS (Central Plains), 1732Z/ 22 May 2002. Courtesy AFWA

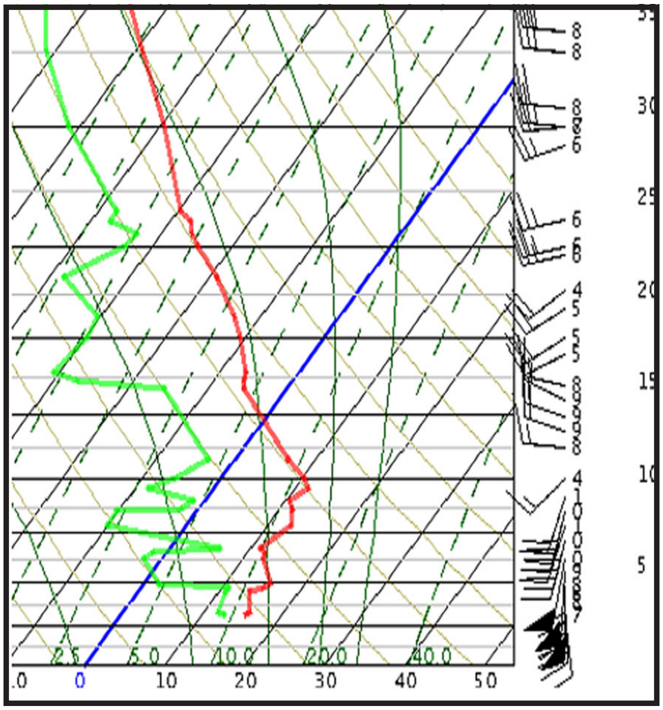

Figure 4-100. KOUN Norman, OK (RAOB), 1200Z/22 May 2002.

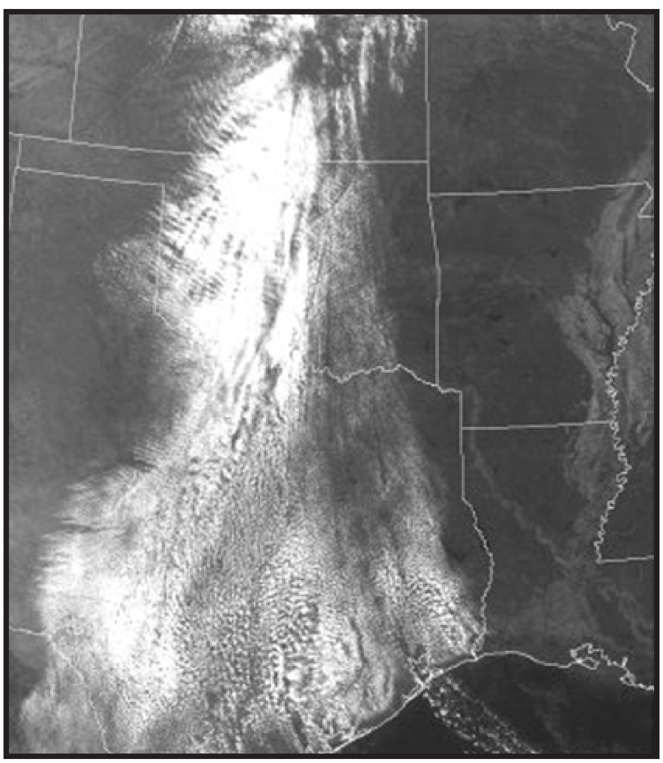

Figure 4-101. GOES E VIS, (South Central Plains), 1732Z/22 May 2002.

Figure 4-102 illustrates the morning surface analysis. A strong east-west pressure gradient is shown across the Great Plains ahead of a maritime polar cold front. Figure 4-103 shows wind profiler locations. Figures 4-104a through 104d depict wind profiler data within the maximum jet stream axis from Oklahoma to Nebraska. In each figure, 50 to 60 knots are evident during the 1200Z to 1300Z time period. The wind velocities decrease somewhat within the lower levels later in the morning.

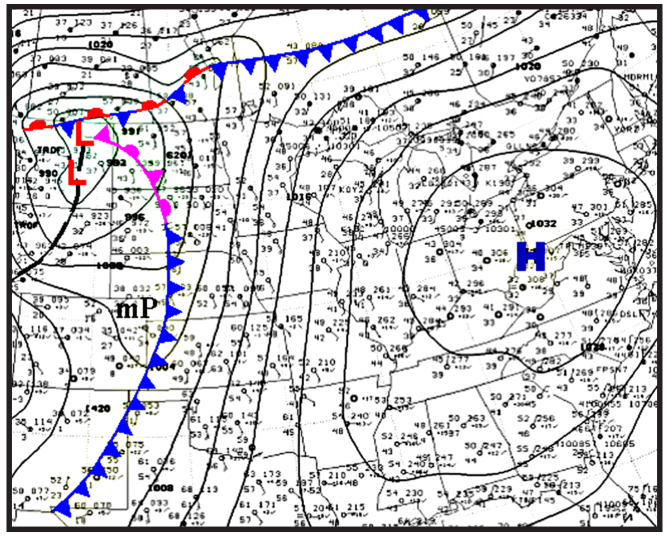

Figure 4-102. Surface, 1200Z/22 May 2002.

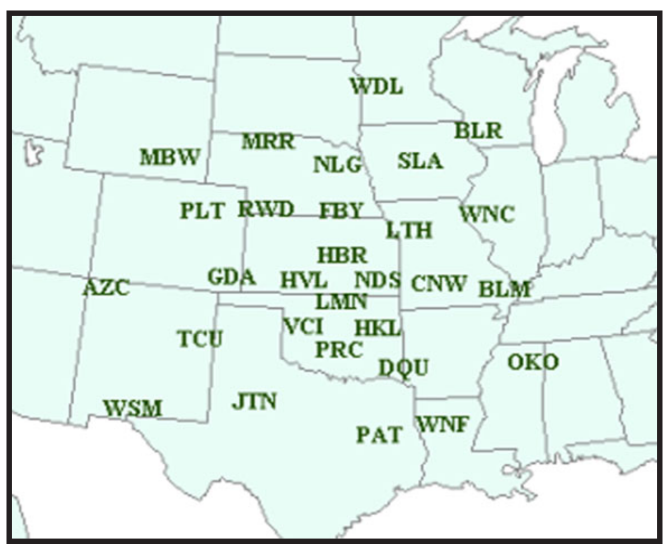

Figure 4-103. Wind Profiler Locations.

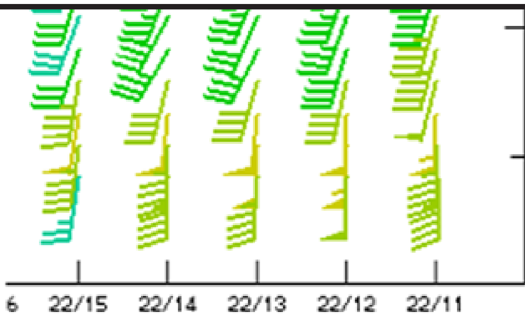

Figure 4-104a
KPRC Purcell, Oklahoma 22 May 2002

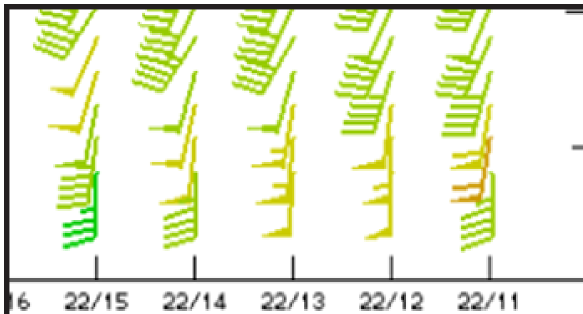

Figure 4-104b
KLMN Lamont, Oklahoma 22 May 2002

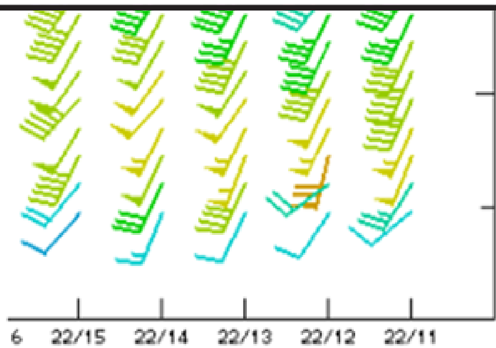

Figure 4-104c
KHBR Hillsboro, Kansas 22 May 2002

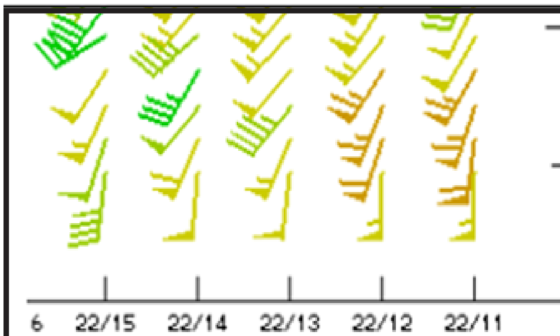

Figure 4-104d
KFBY Fairbury, Nebraska 22 May 2002

General Convection

The convection season across the nation generally begins in April. Considerable thunderstorm activity occurs in May and June and continues throughout summer. Severe thunderstorms and tornado events occur almost daily somewhere east of the Rocky Mountains. Frontal boundaries, convergence zones, land and sea breezes, orographic lifting, strong surface heating and CAPES, and mid-level cold troughs/pockets are excellent features for the production of thunderstorms. May is very active for severe thunderstorm activity due to increased low-level moisture, instability and insolation that interact with cold and warm fronts, surface troughs and convergent zones. Widespread convection over the central and eastern CONUS is not uncommon during May and June, as depicted in Figure 4-105. The frequency of occurrence of mostly frontal-generated thunderstorms (and severe thunderstorms) generally decreases by mid-June across the central and southern Great Plains, as the subtropical high regime becomes established which shifts frontal activity into the upper CONUS and Canada (see *Summer Regimes* for further information).

Forecasters should keep in mind that outflow boundaries left over from nocturnal activity, weak frontal zones that may be discontinued on analyses, convergence zones in the wind fields, and upper cold troughs or combinations thereof will produce smaller scale thunderstorm events. Continuity on old stationary fronts that have weakened to the extent that they may be difficult to locate on surface and/or boundary layer charts must be followed. Convection may develop quickly along these old boundaries when the air mass is moist and highly unstable.

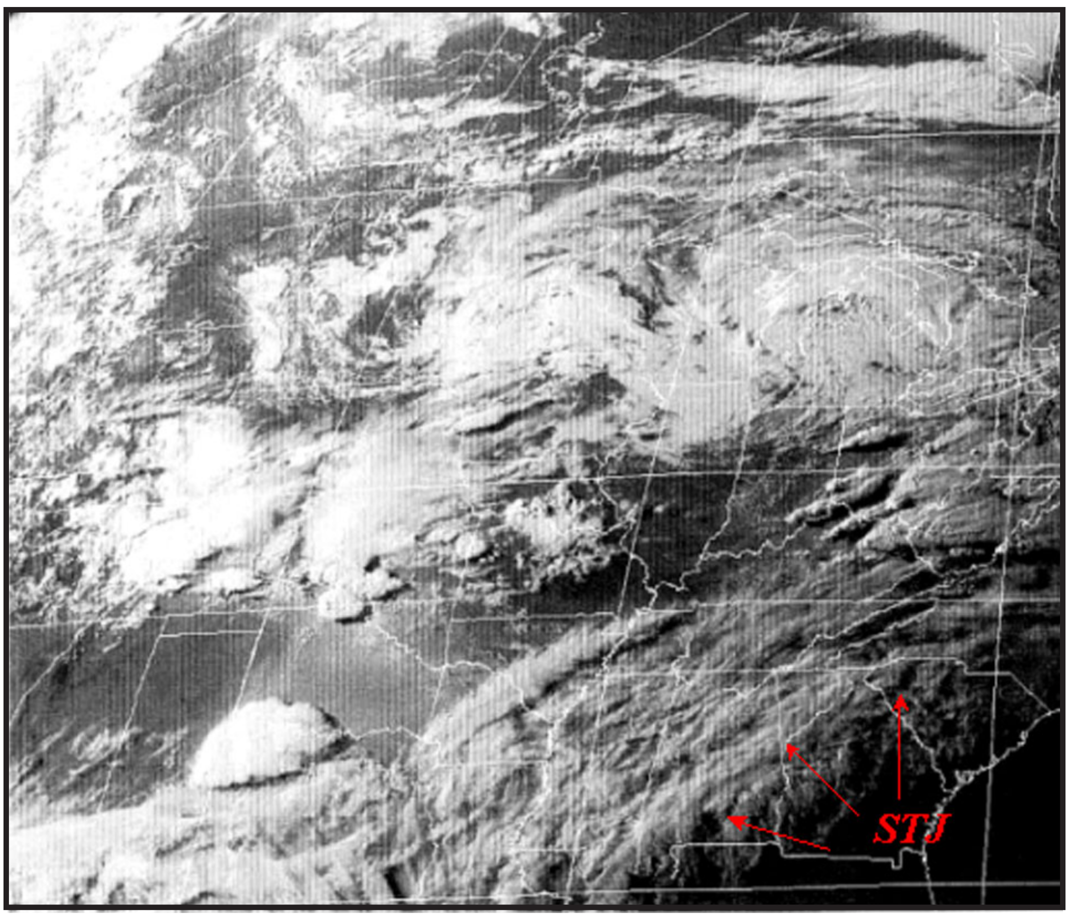

Figure 4-105. GOES E VIS, 2345Z/24 May 1998. In this late afternoon photo, widespread convection has developed from the Rocky Mountains to the East Coast. The subtropical jet (STJ) lies across the southern CONUS.

Cold Frontal Convection

Discussion on cold frontal thunderstorms will be limited to some satellite photos shown in Figures 4-106a through 4-106d. The cold frontal thunderstorm regime on a synoptic-scale occurs often during April and May when the air mass ahead of the cold front is moist enough to produce convection as shown in four examples in figure sequence 4-106. Arrows shown in Figure 4-106b mark developing thunderstorms.

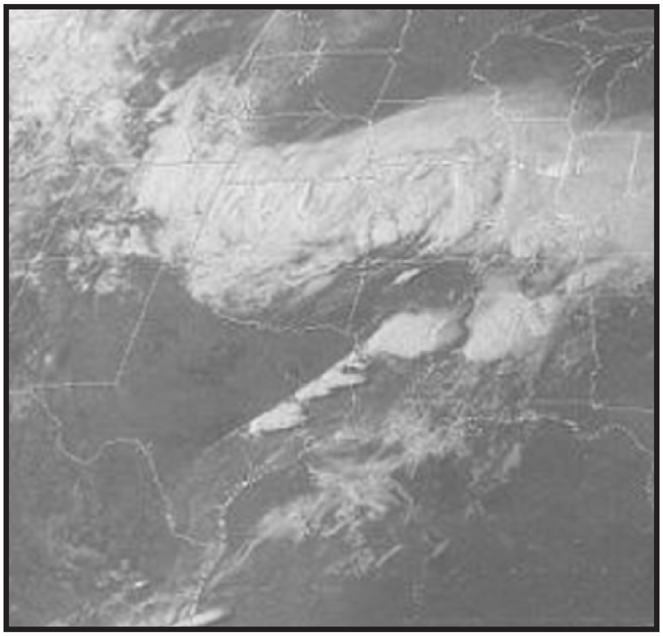

Figure 4-106a. GOES E VIS, 2230Z /18 May 1981.

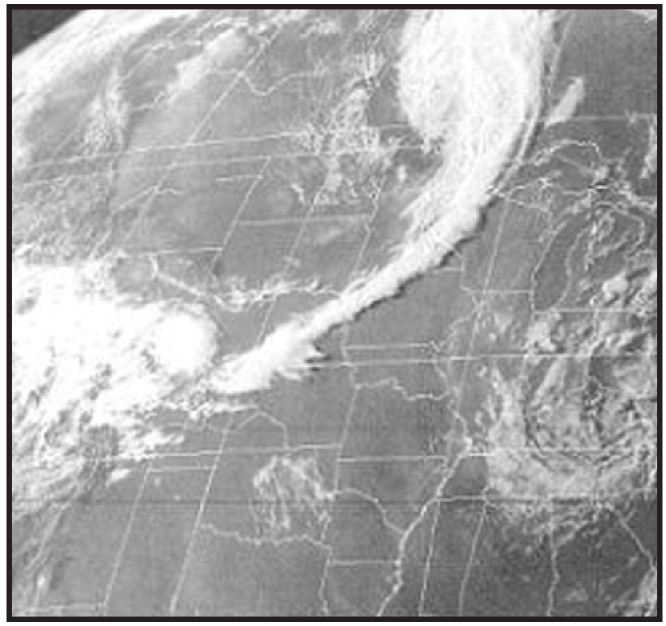

Figure 4-106c. GOES E VIS, 2332Z/4 May 1998.

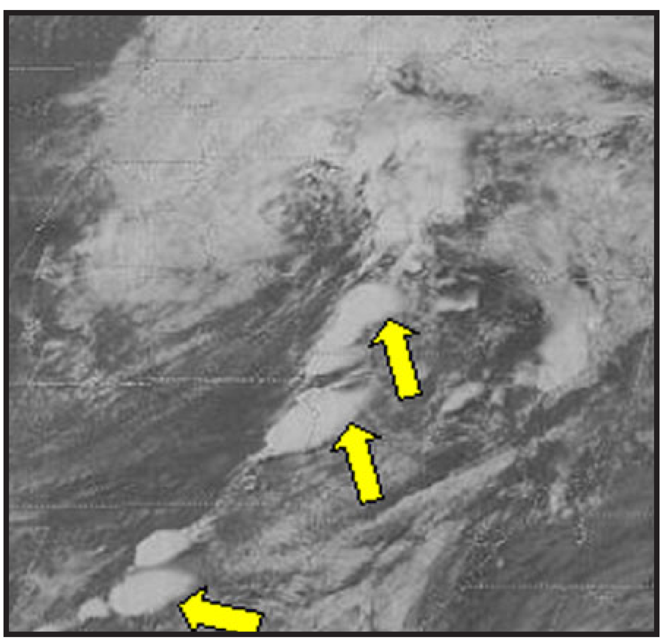

Figure 4-106b. GOES E VIS, 2100Z/23 May 1981.

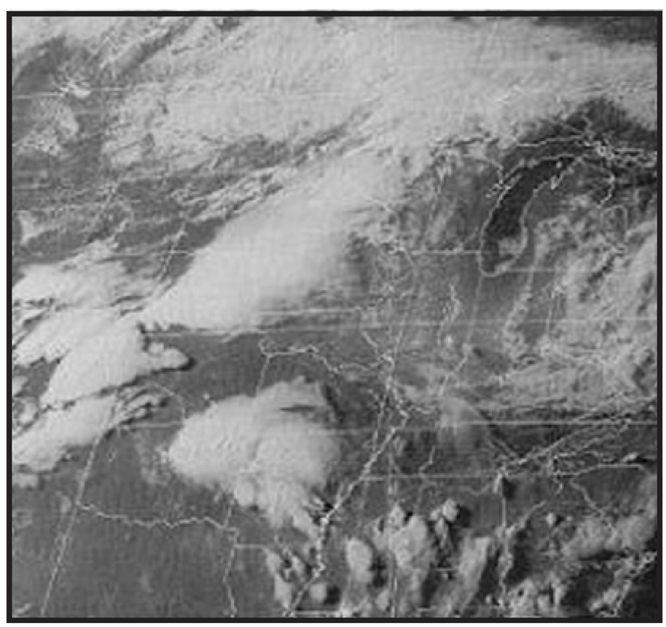

Figure 4-106d. GOES E VIS, 2322Z/22 May 1999.

Warm Frontal Convection

Forecasters should pay attention to the intersection of the low-level jet (and accompanying gulf moisture) with warm and/or east-west oriented quasi-stationary fronts east of the Rocky Mountains. Elevated convection over warm fronts occurs when cP cold fronts become stationary and eventually become warm fronts (see Figure 4-110). Warm frontal severe thunderstorms are not uncommon during April and May east of the Rockies (Figure 4-107). Large hail occurs frequently due to the wet-bulb zero temperature occurring at lower elevations. Forecasters should not be complacent that warm fronts are not associated with convection, although textbooks typically depict warm frontal cloud types as stratiform.

Example 1 – 21 April 1999

Figures 4-107 shows an example of warm frontal thunderstorms that are visible from Iowa to Ohio as noted by a yellow arrow.

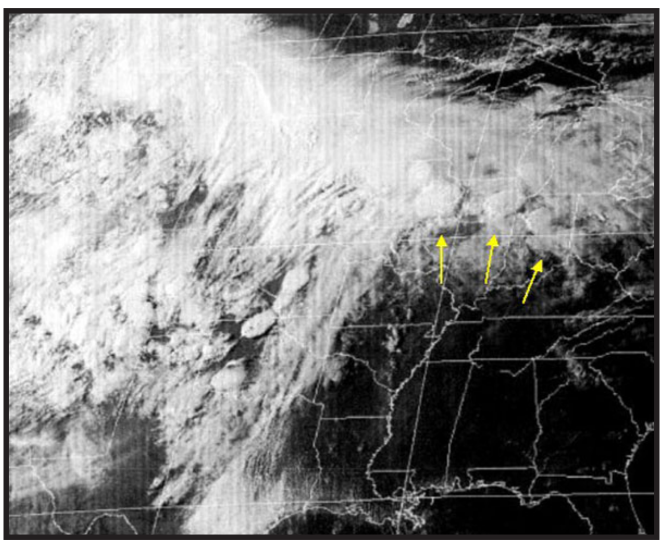

Figure 4-107. GOES E VIS, 2310Z/21 April 1999. Warm frontal thunderstorms are visible from Iowa to Ohio as noted by the yellow arrow. Cold frontal thunderstorms are developing from eastern Nebraska to western Texas.

Example 2 -- 5 June 2001

Figures 4-108 and 4-109 illustrate another warm frontal thunderstorm event. In Figure 4-108, thunderstorms are reported north of the warm front over southern Wisconsin and eastern Iowa. The water vapor photo shown in Figure 4-109 is approximately 12 hours later and reveals cold frontal convection over the central plains and warm frontal convection from Iowa eastward into the Ohio Valley to the East Coast.

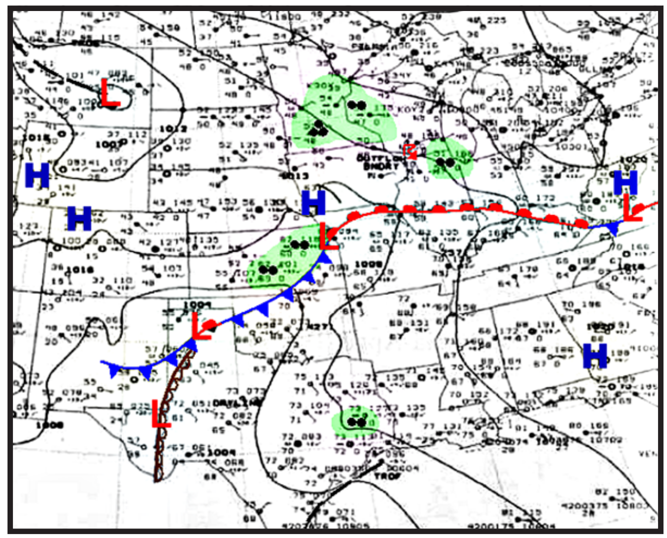

Figure 4-108. Surface, 1200Z/5 June 2001.

Warm Fronts, Squall Lines and Mesocyclones

The intersection of a squall line or active cold front with a warm front is very effective in increasing the severity of thunderstorms. This situation may evolve into a mesocyclone at the point of intersection. The point of formation of the mesocyclone may be forecast by noting the intersection of the warm front with the axis of the low-level (below 6,000 feet) jet. Also, very rapidly falling pressures just north of the warm front and in line with the low-level jet precede formation of the mesocyclone.

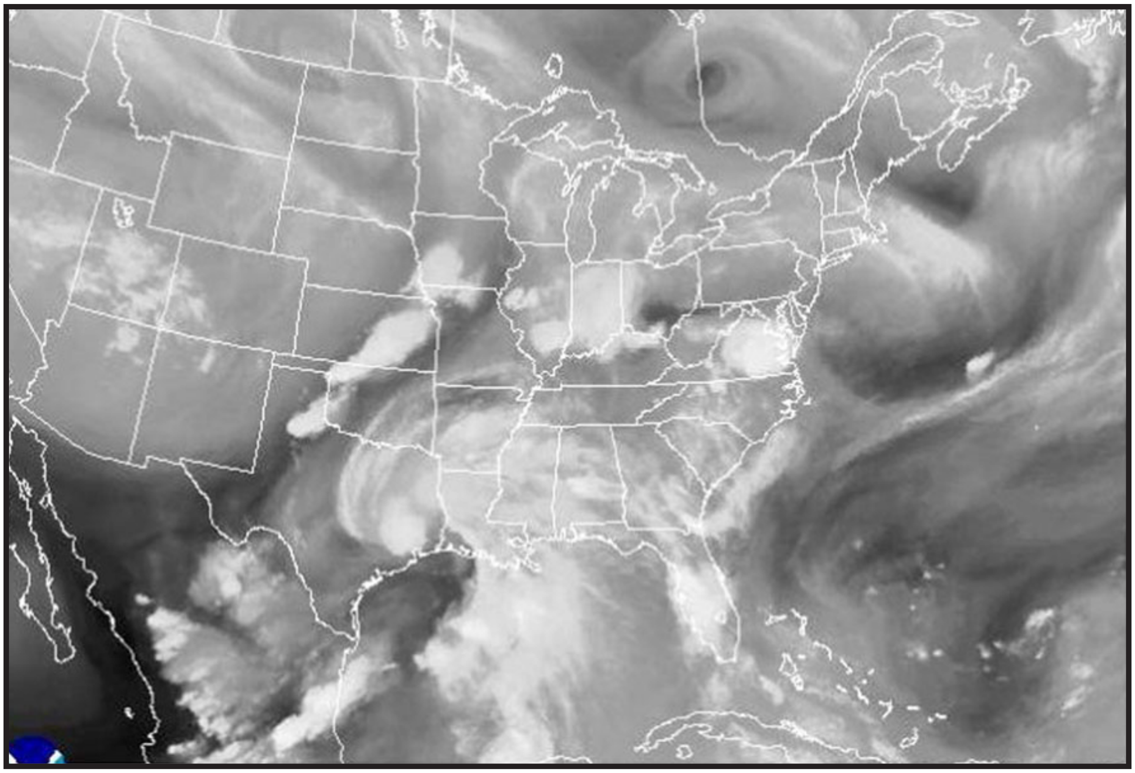

Figure 4-109. GOES E WV, 0045Z/6 June 2001. Cold and warm frontal convection can be seen over the central areas of the CONUS. The cyclonic circulation shown over Texas and Louisiana is a 500-mb cutoff low.

As the squall line approaches, the mesocyclone deepens rapidly and the severe weather phenomena are confined to the immediate vicinity of the warm front. Relatively small areas of destructive storms, with widths of perhaps only 50 to 100 miles will occur. Figure 4-110 exemplifies a model for the development of warm frontal severe thunderstorms. *(See TR 200 (Rev)*, *Chapter Four for more detailed information*).

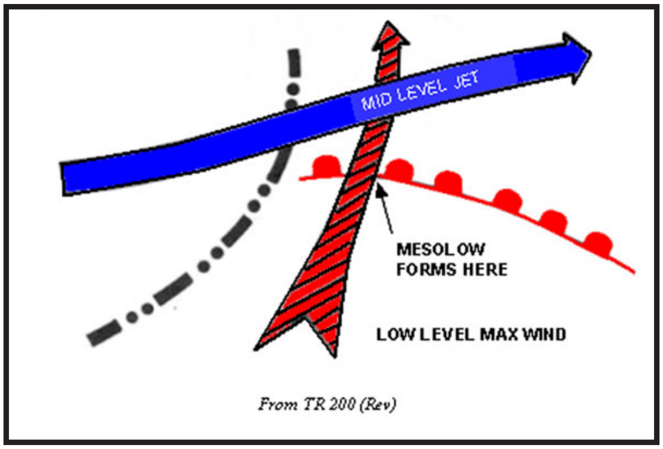

Figure 4-110. Model, Warm Front, Squall Line and Mesocyclone Development. ***From TR 200 (Rev)***

Stationary Frontal Convection

As has been presented earlier in this Chapter, an increase in stationary and/or slow-moving frontal systems over the CONUS are likely, as the westerlies and associated jet streams shift northward with the approach of summer. Figures 4-111 through 4-114 show two examples. In Figures 4-111 and 4-112, the occluded low system is shown over central Canada and the cold front has become stationary and trails east to west over the northern CONUS. Plenty of low-level moisture south of the stationary front is shown over the central and southern plains in Figure 4-111. Three hours later, Figure 4-112, thunderstorms have developed all along the front from Michigan to Wyoming.

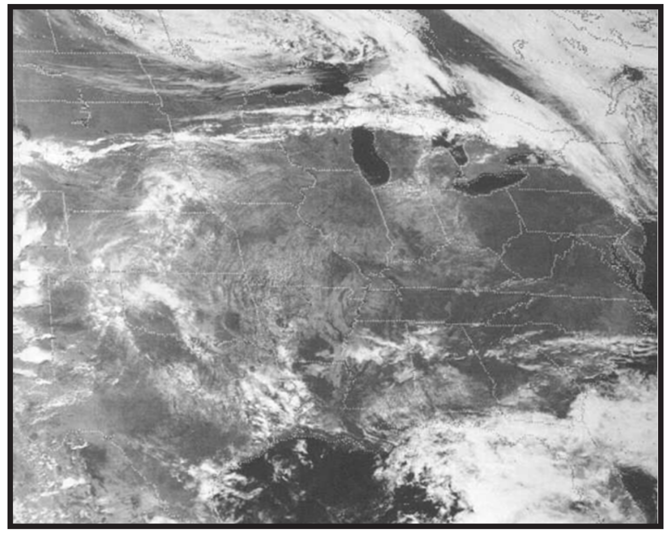

Figure 4-111. GOES E VIS, 2010Z/19 May 1985.

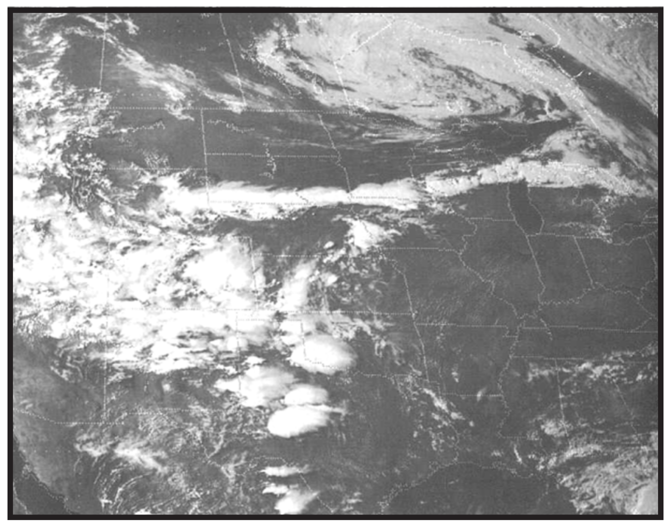

Figure 4-112. GOES E VIS, 2320Z/19 May. 1985.

A similar event is shown in these early June photos, Figures 4-113 and 4-114. In Figure 4-113, an occluded low system is shown over the Dakotas. Thunderstorms exist all along the cold front from Minnesota to Oklahoma. The following day (26 hours later) the cold front over the Great Plains has become stationary and is oriented east to west. Thunderstorms developed all along the stationary front as shown in Figure 4-114. These two photos reveal how conditions can change within a 24-hour period.

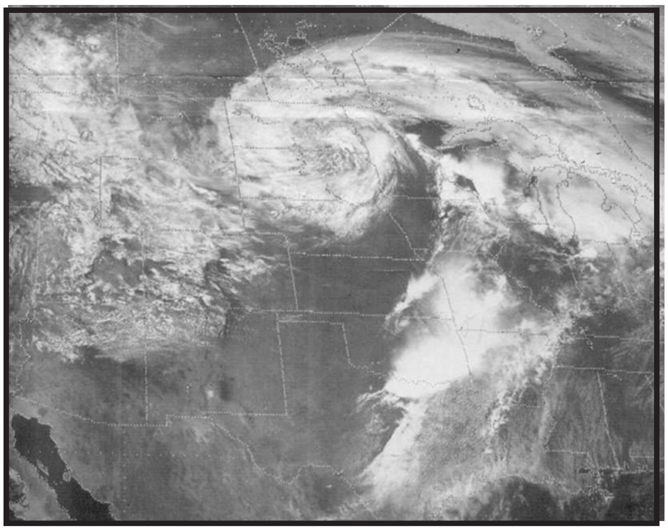

Figure 4-113. GOES E VIS, 1830Z/8 June 1993.

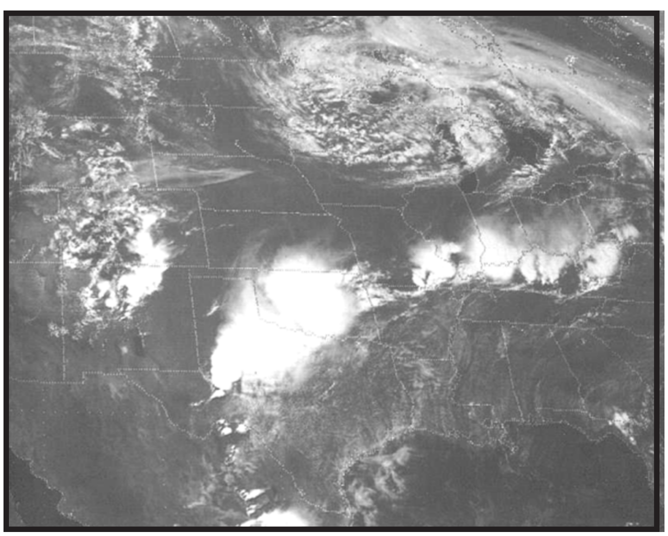

Figure 4-114. GOES E VIS, 2030Z/9 June 1993.

Many thunderstorm events that persist throughout the nighttime hours over the central CONUS began during daytime heating along stationary fronts (Figure 4-115).

Convergent Zones

Many severe outbreaks of convective activity occur along instability lines that develop within convergence zones and moisture axes. Moisture axes generally lie to the east of convergence zones (e.g. dry lines) in advance of mP cold frontal systems. Several examples of thunderstorm development associated with surface convergence and troughs will be shown, since severe thunderstorms are prevalent in spring.

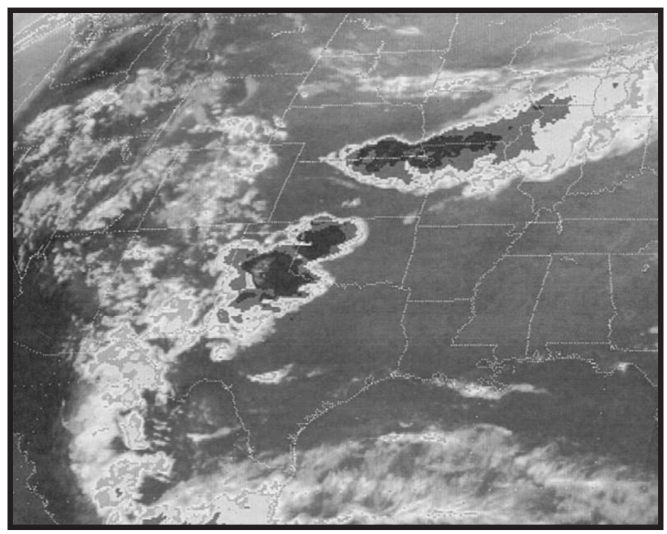

Figure 4-115. GOES E IR, 0100Z/25 May 1983. Evening thunderstorms are shown along a stationary front over the northern plains. Dry line thunderstorms are noted over western Oklahoma and Texas.

Example 1 – 17-18 May 1981

In the first example, Figure 4-116, a Colorado Low has developed east of the mountains. Extensive warm frontal overrunning is shown over the central and northern Great Plains. The first convective activity usually develops on the western side of the low-level convergence zone and travels eastward. The reason for this is that the vertical motions are strongest here, the moisture content is highest, and the solar insolation reaching the ground is greater in the clear air just west of the region. The convergence zone is usually visible when low clouds are present, though it sometimes is quite far in advance of the cold front (see Figure 4-116, noted by the arrow). If the low-level clouds are visible, you will often see a tongue-shaped zone of small cumulus clouds streaming south-to-north and perhaps spiraling toward the center of the advancing low-pressure system. If a cirrus shield exists, forecasters may have to rely on conventional wind data and streamlines analyses to determine the areas of greatest low-level convergence, and on dewpoint analysis to locate areas of greatest humidity, to determine the most active regions. Many tools are available today to determine the degree of instability such as CAPES, Lifted Index, Skew-T, SWEAT Index and Total-Totals Index.

Figure sequence 4-116 through 4-118 illustrates convective development in zones of low-level convergence. In Figure 4-116, a storm system is shown over the western Great Plains. Extensive overrunning of the warm front is noted. In all three of the figures, an area of Gulf moisture advection (stratus) ahead of the cold front intersects the warm front. The first thunderstorms occurred around 2200Z along the dry line. Thirty minutes later, the thunderstorm line has developed southward along the convergent zone as noted by the long white arrows in Figure 4-117. The thunderstorms can be seen extending from south central Oklahoma into northwestern Missouri. The line continued to develop and became a squall line as it moved further away from the cold front.

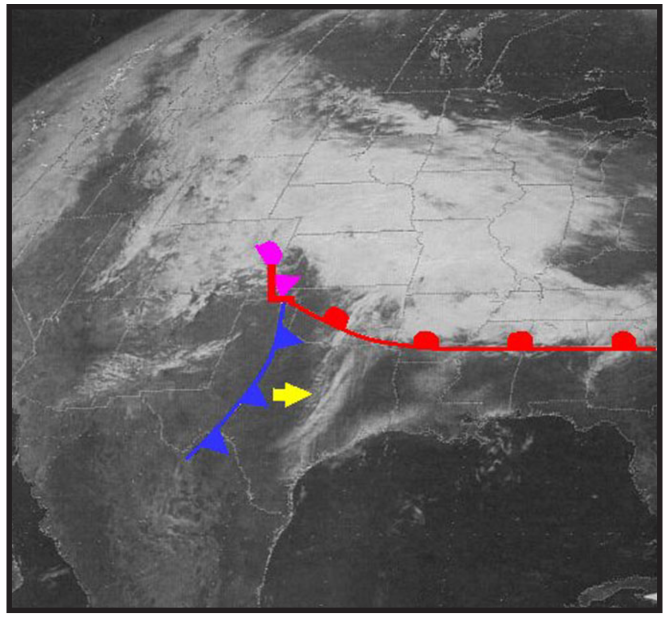

Figure 4-116. GOES E VIS, 1730Z/17 May 1981.

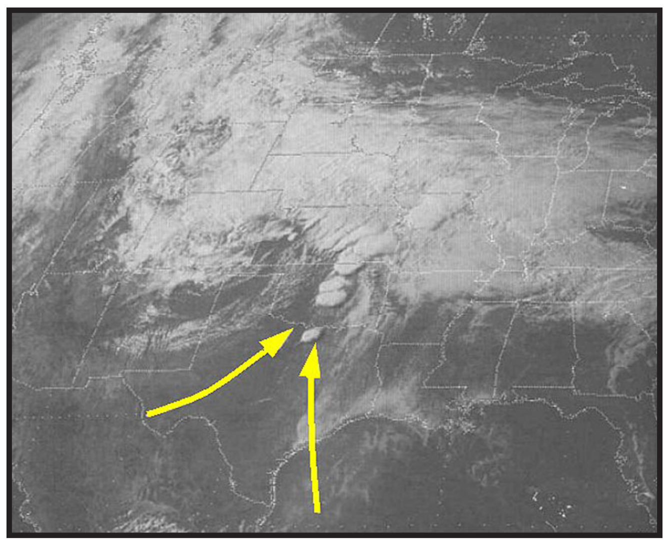

Figure 4-117. GOES E VIS, 2230Z/17 May 1981. Western long arrow represents drier cT air. Eastern long arrow represents moist mT air.

This squall line moved eastward throughout the night and was evident over the lower Mississippi Valley the following morning, as shown in Figure 4-118.

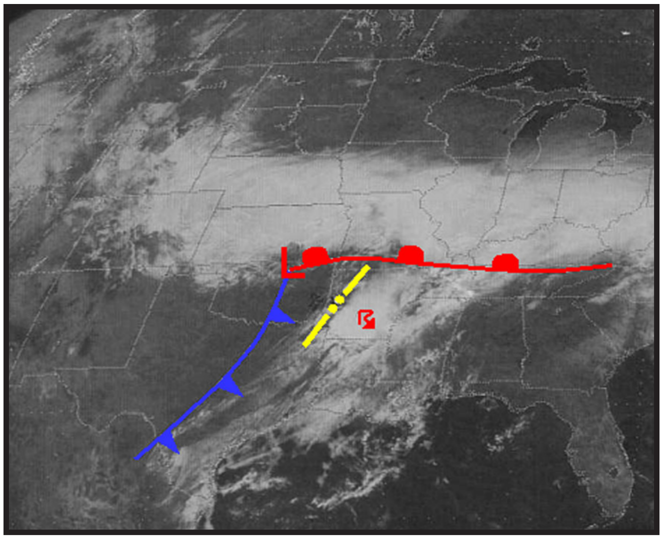

Figure 4-118. GOES E VIS, 1630Z/18 May 1981.

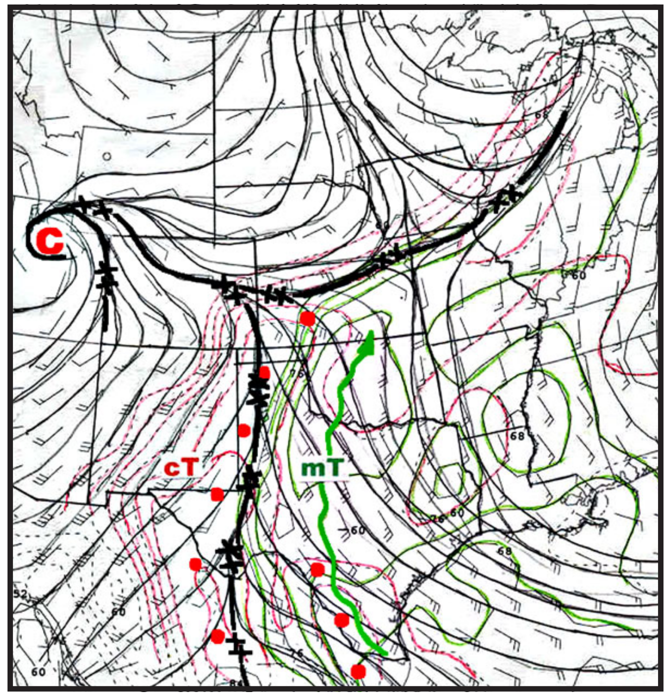

Figure 4-119. BNDRY LYR, 0000Z/22 April 2000. Convergent area (N. Central Mexico to Eastern Colorado) separates cT air from mT air.

Example 2, Western Great Plains Dry Line

A spring and summer convergent regime that occurs often east of the Rocky Mountains and across the western Great Plains is a surface and low-level convergence zone. This zone is called the *dry line* – a zone that separates warm, dry southwest continental tropical (cT) air on the west side from cool, moist southeast maritime tropical (mT) air on the east side is illustrated in Figure 4-119. The dry line is also referred to as the "*Dew Point Front* or *Marfa Front*". These boundaries between hot, dry air and warm, humid air occur more often over western Texas and Oklahoma during early spring as shown in Figure 4-120. By late spring and continuing through summer, dry lines will extend as far north as western Nebraska and South Dakota.

The surface chart shown in Figure 4-120 illustrates a classic dry line example. Dew points east of the dry line can range from the upper 50s to low 70s with winds from the southeast. To the west of the dry line, dew points can be in the 20s and 30s, a decrease across the dry line of 40 degrees or more. Likewise, temperatures east of the dry line are likely to range in the 70s to 80s while behind the dry line, temperatures may range into the mid 80s and high 90s. Often, low clouds exist east of the dry line due to Gulf flow, upslope flow and nocturnal cooling. Surface heating generally breaks up these stratus layers, and cumulus dominate by mid-afternoon. Drier air behind the dry line lifts the moist air ahead of it, triggering the development of thunderstorms along and ahead of the dry line. Dry lines during spring are almost always severe weather producers – it is not uncommon for tornadic supercells to develop along a dry line. The most intense dry line thunderstorm activity, both in severity and areal coverage, is associated with short waves approaching the Rocky Mountains. **Dry line convection can develop rapidly and often become severe thunderstorms with tornadoes within an hour.** Forecasters within the dry line convergence zone should react quickly to the threat of severe thunderstorms when the first sign of cumulus lines develops.

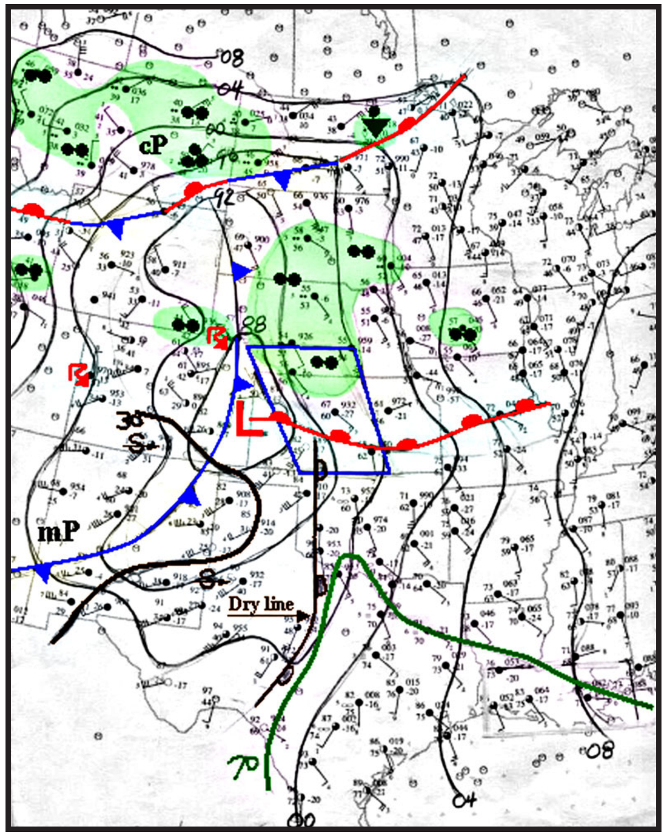

Figure 4-120. Surface, 1200Z/12 May 1995. Strong southwesterly winds, dust and 80-90°F temperatures and < 50°F dew points appeared over western Texas and New Mexico. Seventy-degree dew points with low clouds and fog/haze are shown in green, while the thirty-degree dew point line is noted in brown. A severe thunderstorm watch box is shown over western Kansas where the dry line intersects the warm front.

During most of late spring and continuing through summer, when a southerly flow exists (with no frontal intrusions) across the central and southern Plains, the dry line appears daily over western Texas, Oklahoma and Kansas. The dry line generally drifts back and forth: eastward into the central/southern Great Plains during the heating period and westward into western Texas, Oklahoma and Kansas during the cooling period. Forecasters, anticipating a line of convection to develop rapidly along the dry line during the mid-morning hours, should adjust development of convection a little further to the east from the current dry line position. Note: Dry lines rarely make it into eastern Texas and Oklahoma although the associated dry line thunderstorms will continue eastward. On the other hand, thunderstorms may not develop along the dry line if the air above is capped where warm, dry stable air aloft from the mountains forms a cap (more likely during late spring). If a cap exists over the dry line during maximum heating, convection will likely develop but the cumulus cloud tops will generally remain at or below the inversion. Very strong surface heating and strong CAPES (Convective Available Potential Energy) may break the inversion and produce short-lived dry line thunderstorms.

Example 3, Dry Line Development, 7-8 May 1986

A dry line severe thunderstorm event that occurred over a two-day period is shown in the following selected illustrations. Figures 4-121 through 4-125 depict the first event. Dry line thunderstorm events over the western Great Plains can occur daily when a stationary regime exists, as shown in this example. In this particular event, a major trough was stationary west of the Rocky Mountains, as shown in the heights/vorticity analysis (Figure 4-121). Strong upper level ridging existed over the eastern CONUS. Afternoon dry line convection occurred over several days due to the stationary pattern. The associated surface features are shown in Figure 4-122.

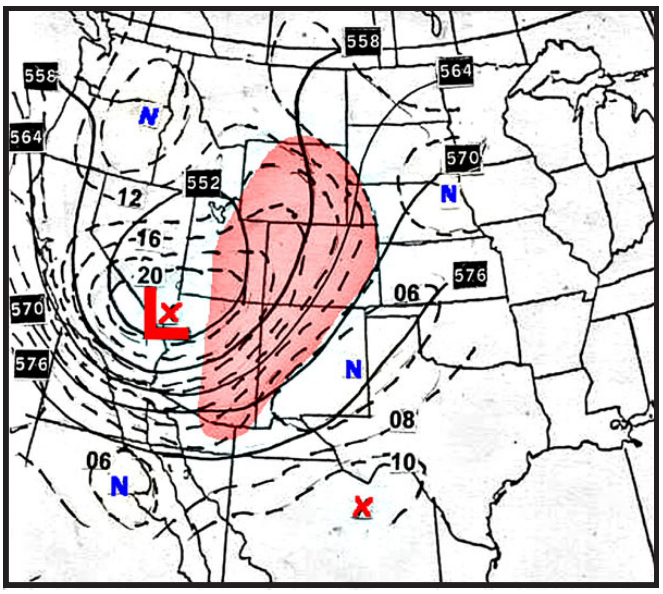

Figure 4-121. 500MB HEIGHTS/VORTICITY, 1200Z/7 May 1986.

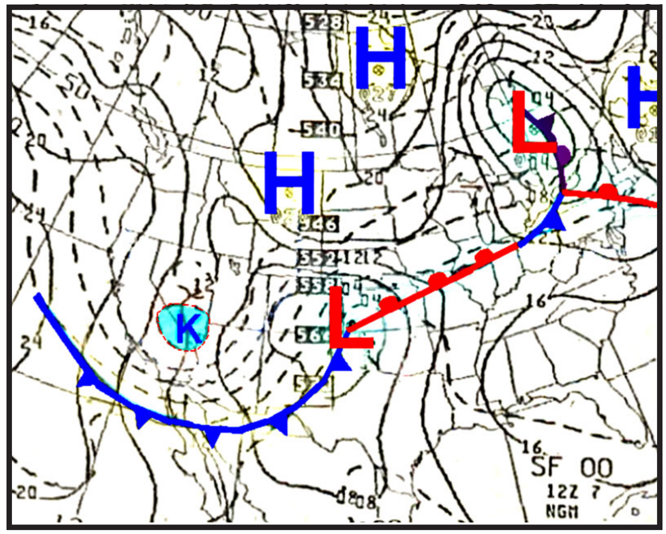

Figure 4-122. Surface, 1200Z/7 May 1986. The cold front shown over Eastern New Mexico did not move out into the Great Plains for the next 24 hours.

Figure 4-123 shows the morning 850mb analysis. An east-to-west frontal boundary exists over northern Kansas. Thermal and moisture axes and low-level jets are shown south of the front. Moisture (as indicated by M) has pooled from the Texas Panhandle to Missouri area.

Selected visible satellite photos depicting dry line thunderstorm development during the heating hours are shown in Figures 4-124 through 4-126. In the late morning photo, Figure 4-124, gulf moisture extends from southern Texas to Kansas. Further development of dry line convection appears in Figures 4-125 and 4-126.

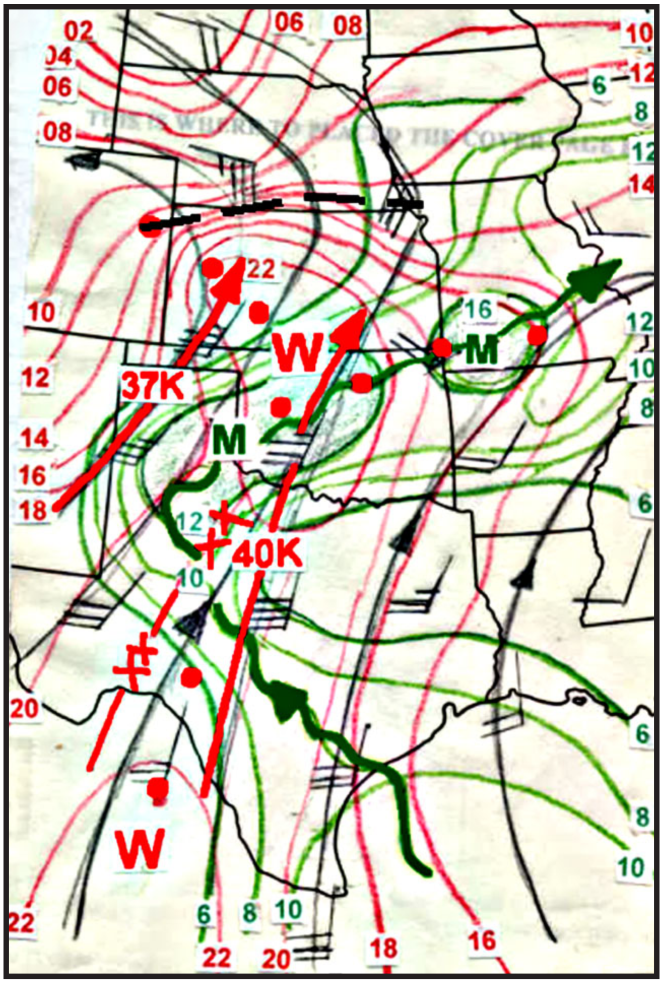

Figure 4-123. 850mb, 1200Z/7 May 1986.

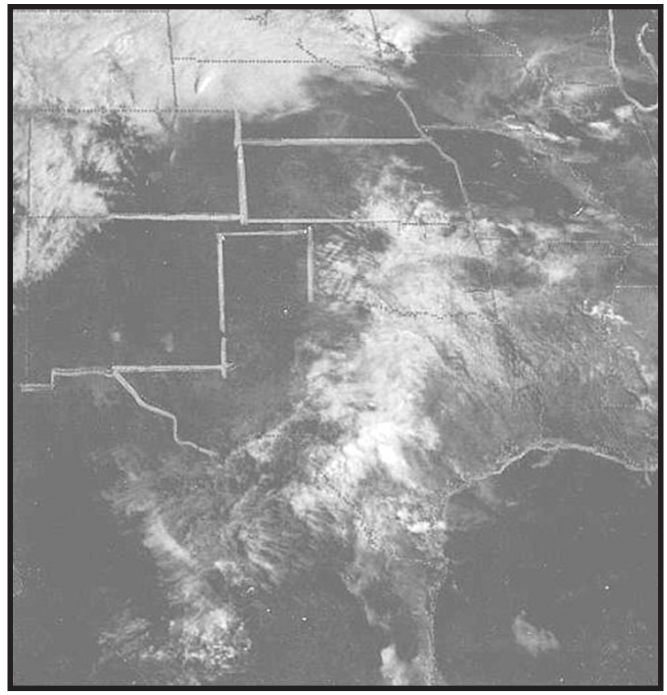

Figure 4-124. GOES E VIS, 1610Z/7 May 1986. Moisture advection location compares favorably with moisture axis shown in the 850mb analysis in Figure 4-123.

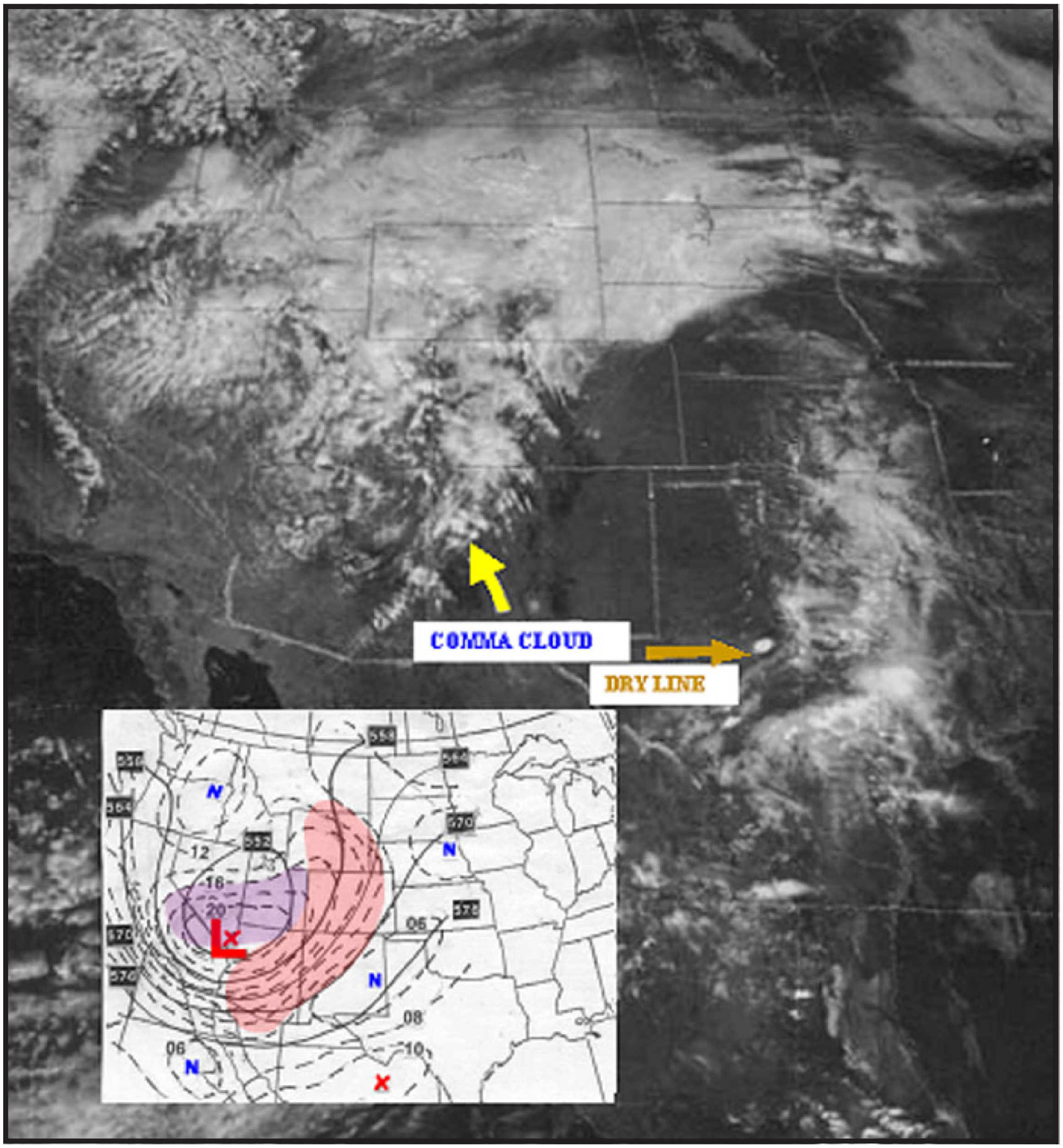

Figure 4-125. GOES E VIS, 1950Z/7 May 1986. INSET: 500mb Heights/Vorticity, 1200Z/ 7 May 1986. A vorticity comma cloud system appears over the Great Basin region as noted by the wider white arrow. The slim white arrow points to the first sign of dry line convection.

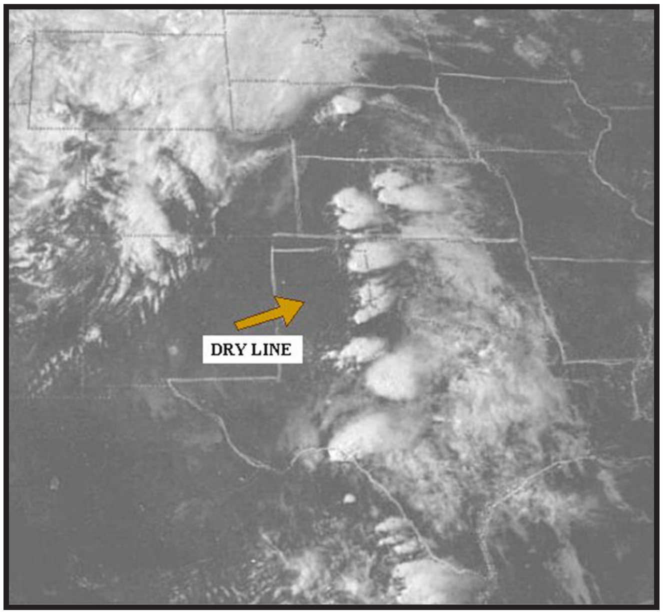

Figure 4-126. GOES E VIS, 2225Z/7 May 1986.

The next day's set of illustrations is shown in Figures 4-127 through 4-135. Figures 4-127 and 4-128 respectively show the morning initial boundary layer and 850mb composites for the significant features. Both composites reveal a strong convergence zone from western Texas to Kansas, which did not appear on the 850mb chart the day before. Southwesterly to westerly winds are shown west of the convergence zone, while southerly winds and a low-level jet prevail east of the zone.

Figure 4-128a shows the symbology for the parameters in Figure 4-128.

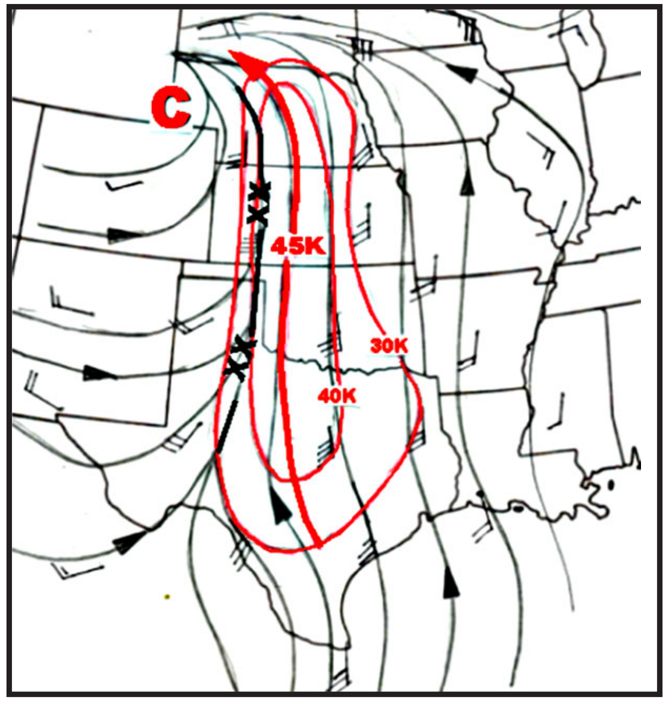

Figure 4-127. BNDRY LYR Composite 1200Z/8 May 1986.

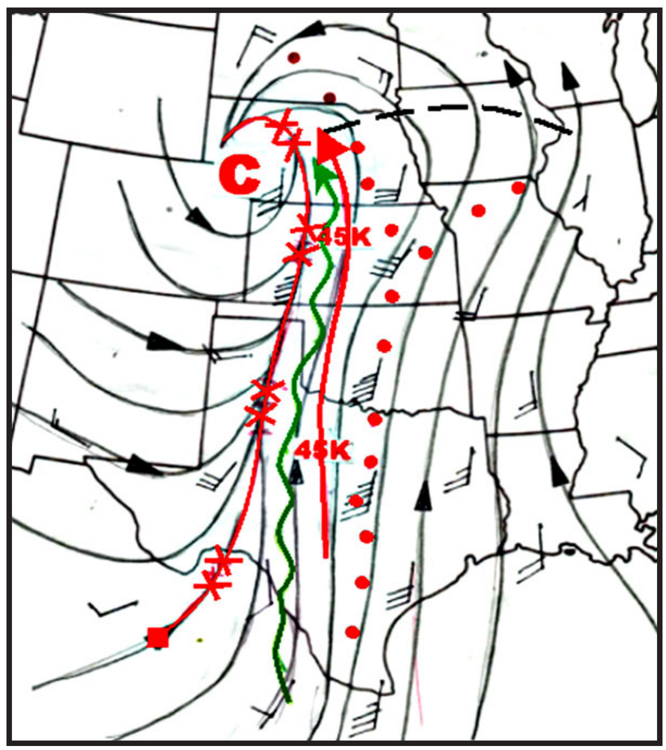

Figure 4-128. 850 mb Composite, 1200Z/8 May 1986. Strong convergence, 45-knot low-level jet, moisture and thermal axes should fire dry line thunderstorms later in the day.

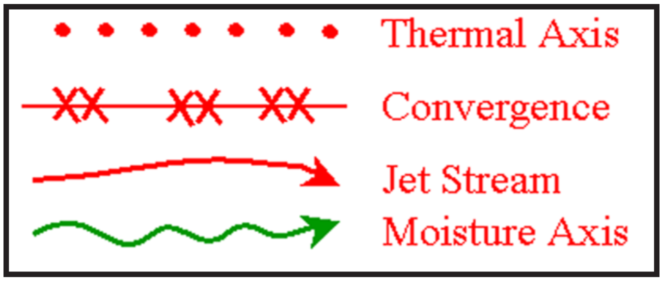

Figure 4-128a. Composite Symbols for Figure 4-128.

Forecasters should pay attention to the mid-level analyses, particularly the 700mb, to see if mid-level dry air has advected northeastward over the lower level moist dry line region. Advection of drier air in mid-levels is a key ingredient for the production of severe thunderstorms. The models' 700mb Heights/Relative Humidity analyses and forecasts are excellent in following the advection of mid-level dry air into the Great Plains. Figure 4-129 illustrates the morning 700mb Heights/Relative Humidity analysis. Drier air can be seen from western Texas to western Kansas as noted by the brown arrow. The upper low/trough west of the Rockies remained stationary for several days.

The height and vorticity analyses are shown in Figure 4-130. The PVA lobe shown over the Rocky Mountains is not that strong, with little crossing of the vorticity isopleths to the contours. The positive vorticity lobe shown over the central plains (and 700mb-moisture pocket shown in Figure 4-129) did produce severe thunderstorms ahead of the dry line (will be shown later in Figure 4-135).

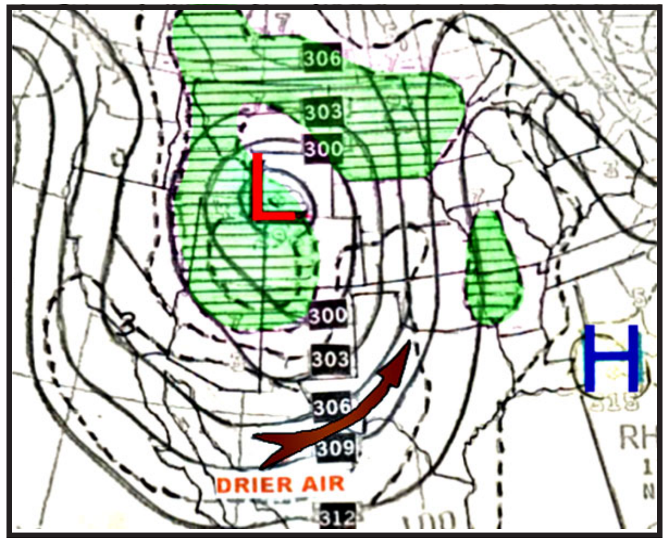

Figure 4-129. 00HR FCST 700 mb Heights/Rel Humidity, 1200Z/8 May 1986.

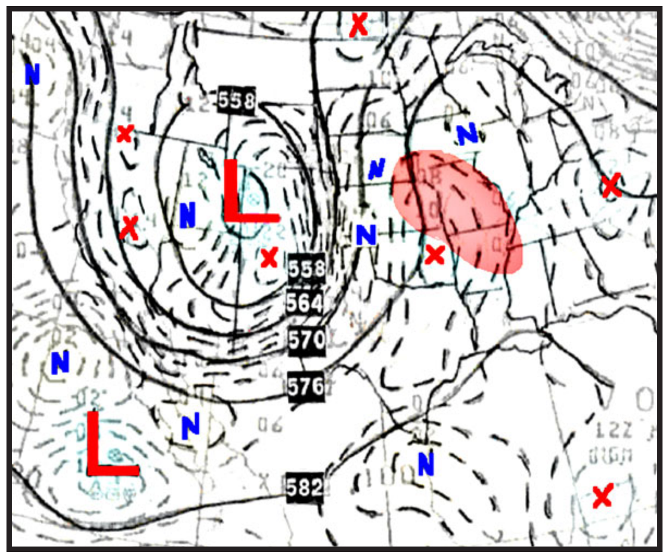

Figure 4-130. 00HR 500MB HEIGHTS/ VORTICITY, 1200Z/8 May 1986.

The next day's dry line convective activity over a six-hour period is shown in Figures 4-131 through 4-133. In Figure 4-131, convection from the previous afternoon, which persisted through the nocturnal period, can be seen from Kansas to eastern Texas. New dry line cells are forming over western Nebraska southward to the Texas Panhandle. Figures 4-132 and 4-133 depict further intensification of dry line thunderstorms over the western Great Plains.

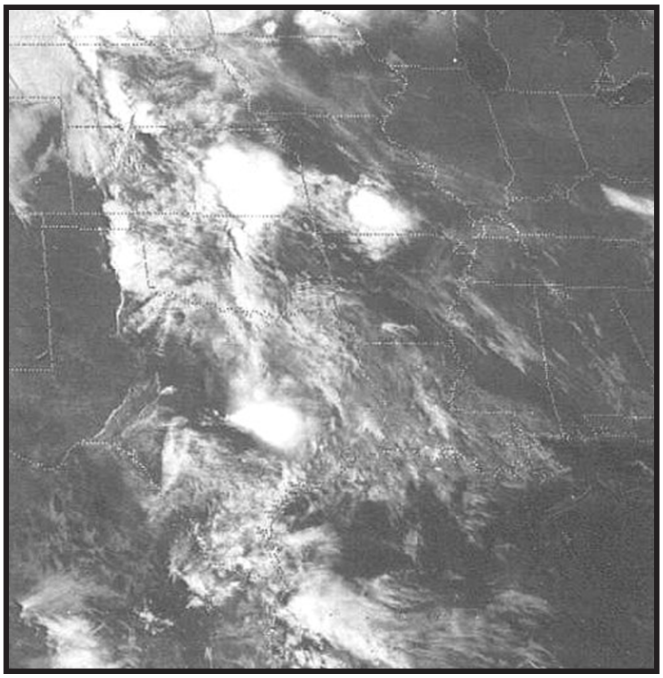

Figure 4-131. GOES E VIS, 1555Z/8 May 1986.

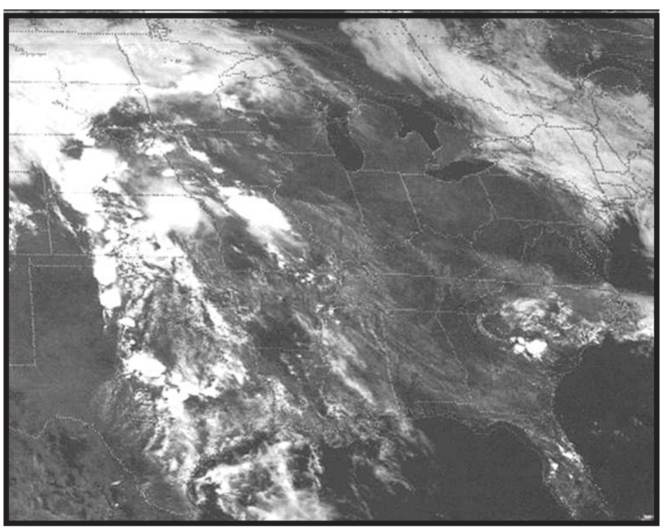

Figure 4-132. GOES E VIS, 1920Z/8 May 1986.

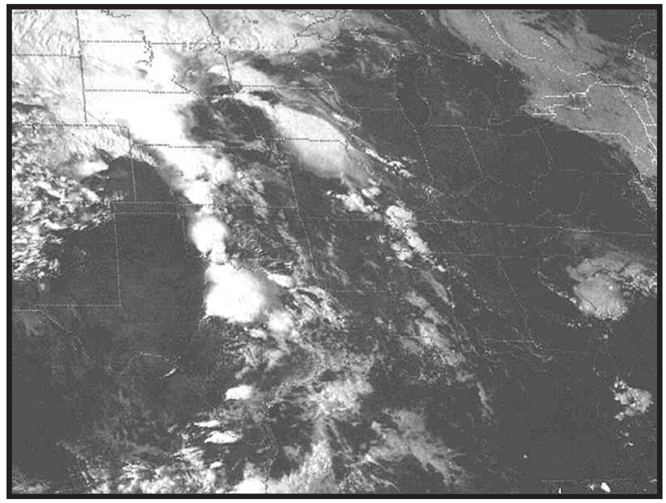

Figure 4-133. GOES E VIS, 2210Z/8 May 1986.

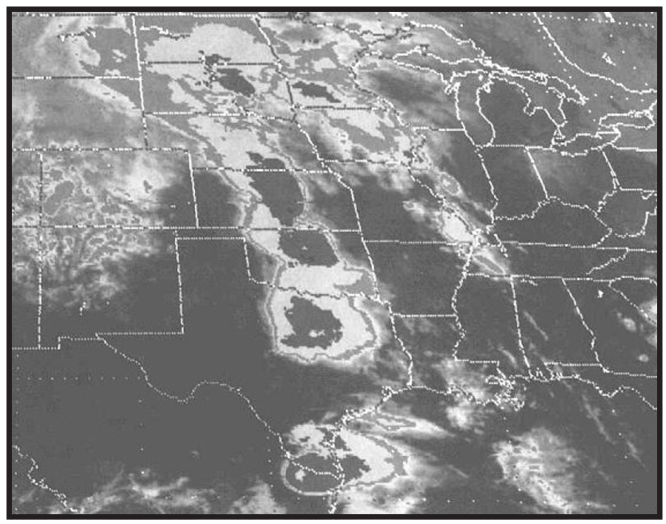

Figure 4-134. GOES E IR, 0107Z/9 May 1986.

Dry line thunderstorms will often persist and expand as the line moves eastward during the evening hours. Low-level moisture and instability that exist ahead of the line enhance continued growth. Figure 4-134 shows an early evening photo of a growing thunderstorm line three hours later from Figure 4-133. These lines generally weaken towards sunrise. Outflow from these weakening thunderstorms may produce new activity by mid-morning.

Figure 4-135 shows reported severe thunderstorm/ tornadoes for the second day event.

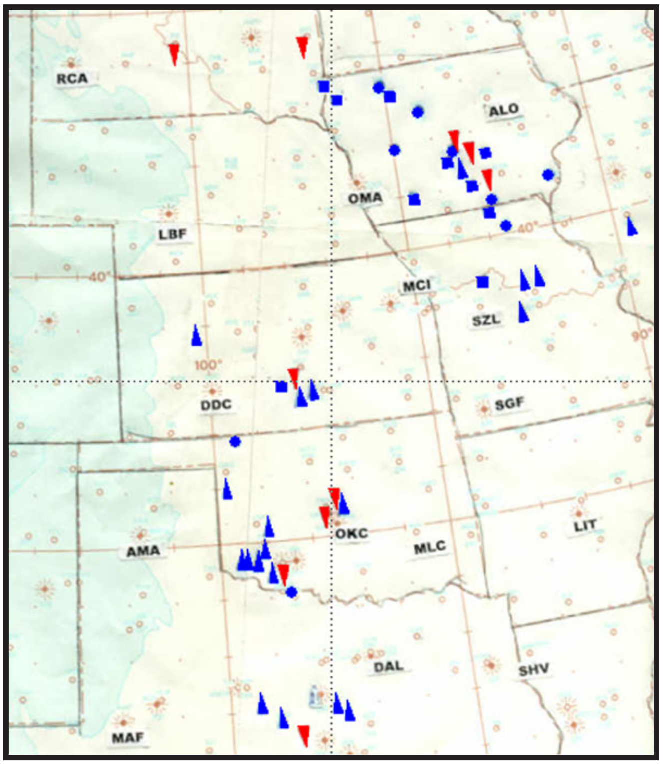

Figure 4-135. Severe Convective Reports, 8 May 1986.

Example 4, Dry Line Convergence, 3 May 1999

This early May event produced many multiple supercell thunderstorms with tornadoes over central and southwestern Oklahoma. The Oklahoma City area was especially hit hard by killer tornadoes. Deaths, injuries and heavy damage also occurred in the Wichita, Kansas metro area. Selected model and analysis data are presented in Figures 4-136 through 4-142. Figures 4-136a and 4-136b depict the NGM initial 500 mb and surface data. In Figure 4-136a, weak PVA is noted over the Great Plains. At the surface, Figures 4-136b, the lee-side trough is shown over the western Great Plains and coincides with the dry line. An mP cold front extends from Wyoming to southern California.

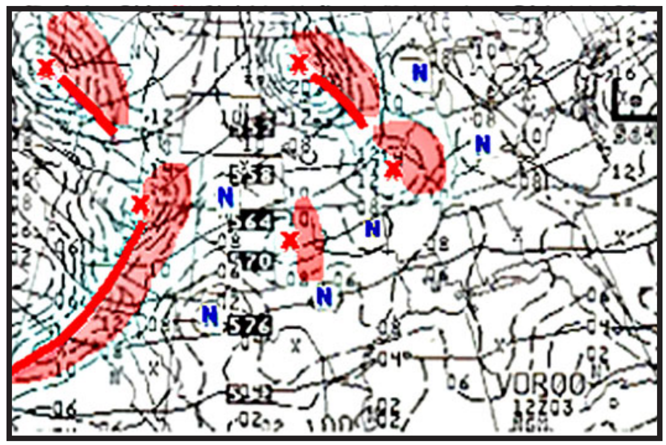

Figure 4-136a. 00HR 500MB HEIGHTS/ VORTICITY, 1200Z/3 May 1999.

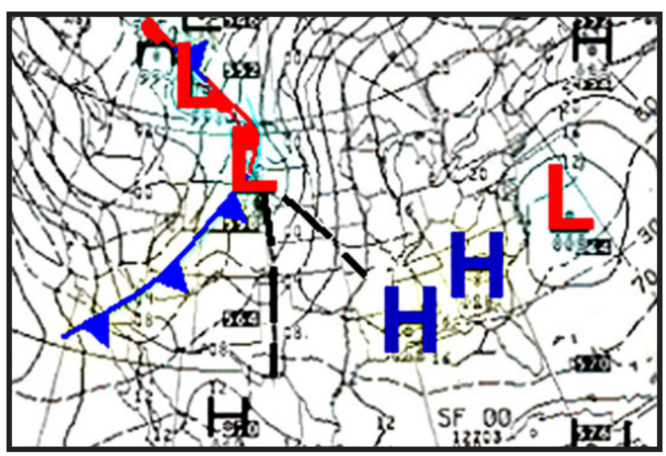

Figure 4-136b. 00HR MSL PRES/1000-500MB THCKNS, 1200Z/3 May 1999.

The NGM 12-hour forecasts are shown in Figures 4-137a and 4-137b. In Figure 4-137a, weak PVA is forecast over the Oklahoma/Kansas area where intense thunderstorms are occurring. In Figure 4-137b, the mP front is forecast over the Rocky Mountains.

The six-hour and 12-hour ETA forecasts are respectively shown in Figures 4-138a and 4-138b. At the six-hour, Figure 4-138a (1800Z), weak PVA is forecast. However, the 12-hour forecast, Figure 4-138b, reveals a strong PVA lobe emerging from the Rockies by late afternoon.

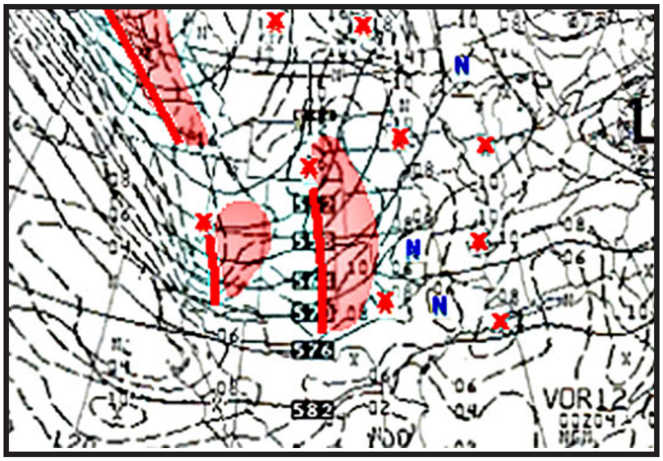

Figure 4-137a. 12HR 500MB HEIGHTS/ VORTICITY, 0000Z/4 May 1999.

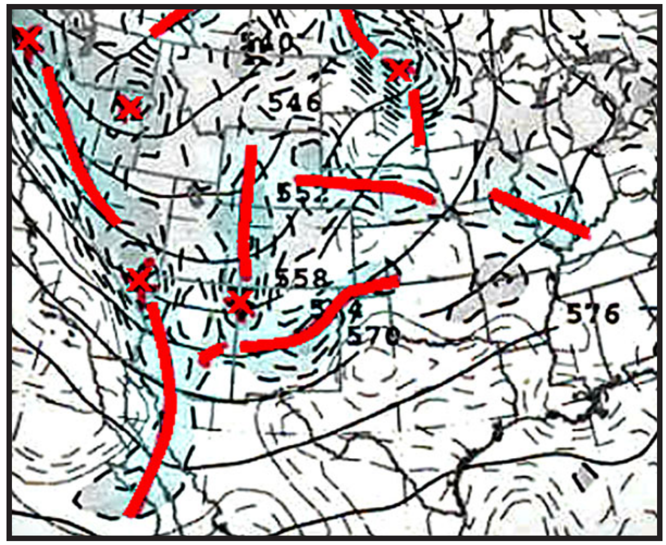

Figure 4-138a. ETA 6HR 500MB HEIGHTS/ VORTICITY, 1800Z/3 May 1999.

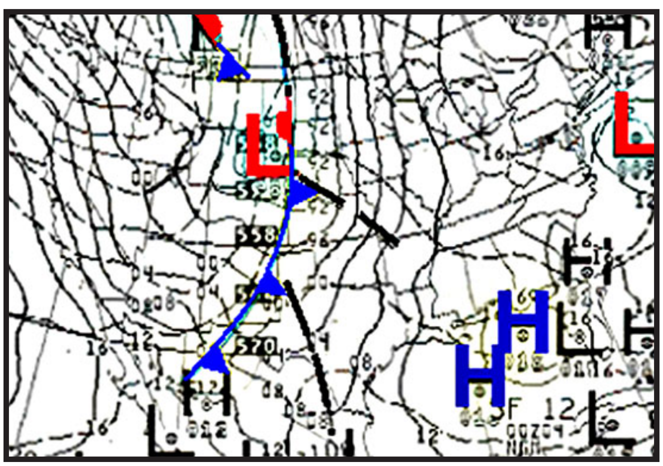

FIGURE 4-137B. 12HR MSL PRES/1000-500 THCKNS, 0000Z/4 MAY 1999.

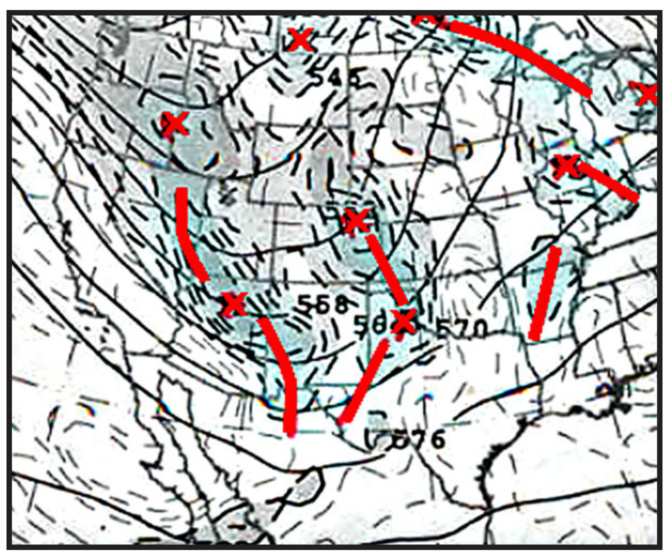

Figure 4-138b. ETA 12HR 500MB HEIGHTS/ VORTICITY, 0000Z/4 May 1999.

The next set of ETA figures show the Lifted Index, CAPE and CINH initial analysis, Figures 4-139a and 4-139b, and 12-hour forecasts, Figures 4-140a and 4-140b. (CAPE: Convective Available Potential Energy and CINH: Convective Inhibition). The morning data shown in Figures 4-139a and 4-139b, depicts strong instability east of the dry line over western Texas to western Oklahoma.

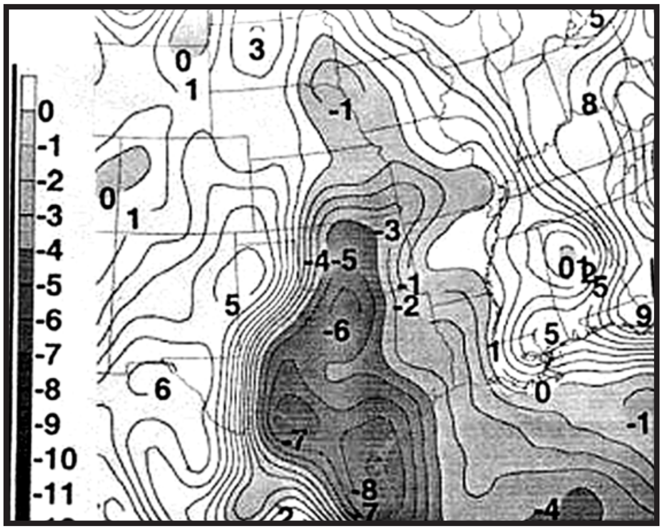

Figure 4-139a. 00HR LIFTED INDEX, 1200Z /3 May 1999.

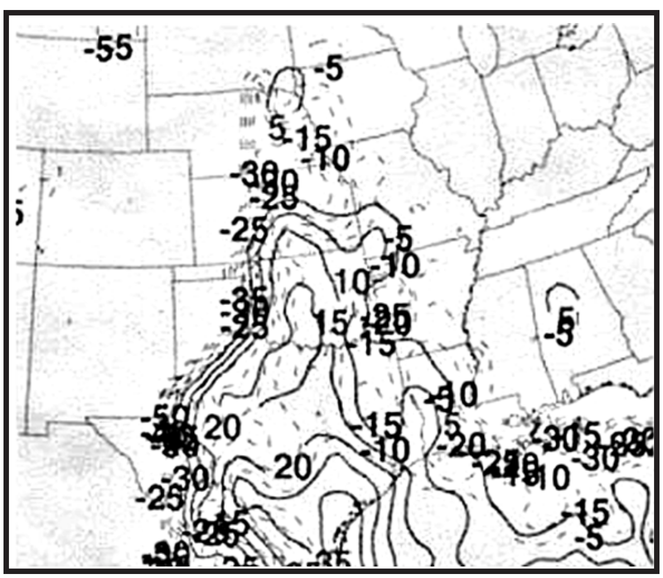

Figure 4-139b. 00HR SFC CAPE (J/KG)X100 00HR SFC CINH (J/KG)X10, 1200Z/3 May 1999.

The ETA 12-hour forecasts are shown in Figures 4-140a and 4-140b. In both figures, strong instability is forecast by late afternoon east of the dry line. At this time, severe thunderstorms with tornadoes occurred over areas of Oklahoma and Kansas.

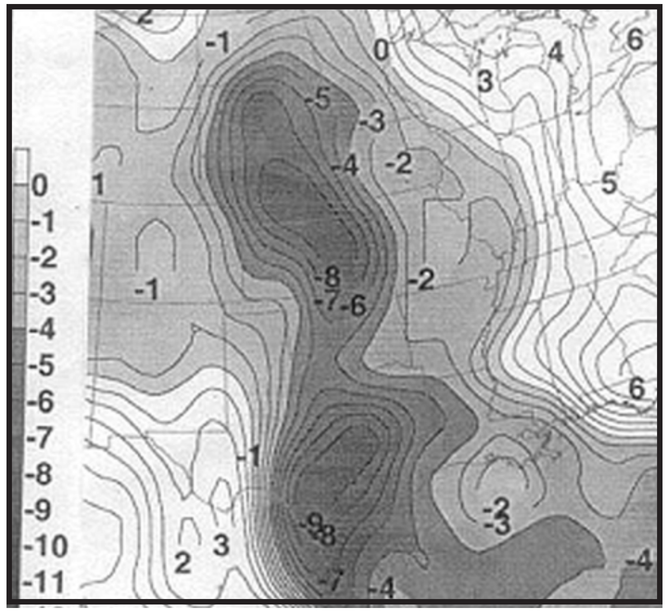

Figure 4-140a. 12HR LIFTED INDEX, 0000Z/4 May 1999.

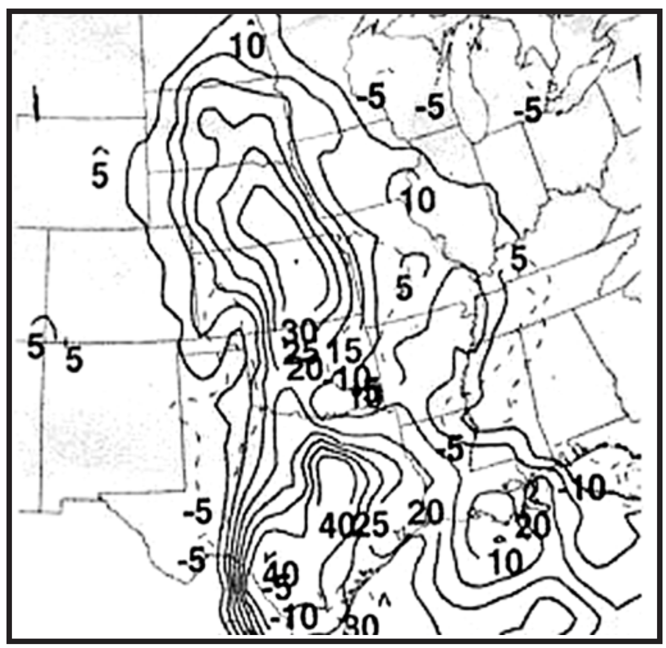

Figure 4-140b. 12HR SFC CAPE (J/KG), 12HR SFC CINH (J/KG)X10, 0000Z/4 May 1999.

The related 1200Z 850mb analysis is shown in Figure 4-141. Gulf moisture advection has reached into Oklahoma. A 30 to 35 knot jet is shown from the Texas Panhandle to Iowa. There is little, if any, directional convergence in this southwest flow. The back edge of the moisture tongue over western Texas and Oklahoma would be considered the dry line in the absence of wind direction convergence. The thermal axis lies to the west of the moisture axis over western Texas and Oklahoma - the air heats, convection develops (along the cloud/clear air boundary) and the developing convection moves into the moisture field.

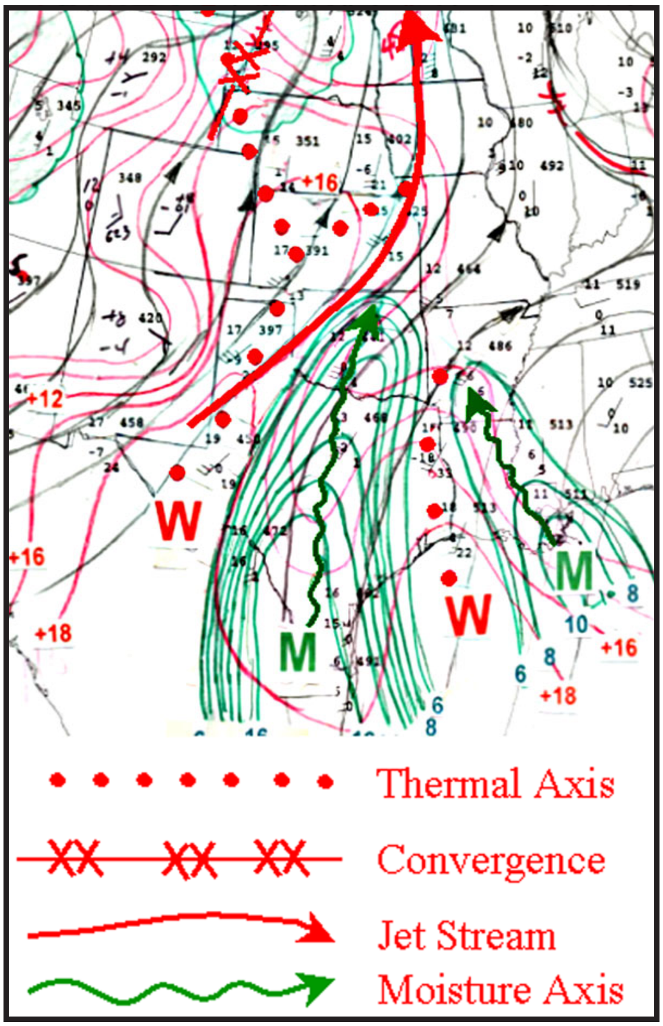

Figure 4-141. 850mb, 1200Z/3 May 1999. Isodrosotherms (°C) are shown in green and are analyzed at 2-degree increments. Temperatures (°C) are shown in red at 2-degree increments. Thermal and moisture axes are included.

The six-hour NGM boundary layer forecast is shown in Figure 4-142. This early afternoon forecast reveals signatures for the development of strong and severe thunderstorms. A low-level jet, thermal and moisture axes, and dry line convergence along with a strong lifted index and CAPES (Figure 4-140a/b) are in place. The mP cold front indicated by convergence over Wyoming is not a factor in this severe thunderstorm event over the Great Plains.

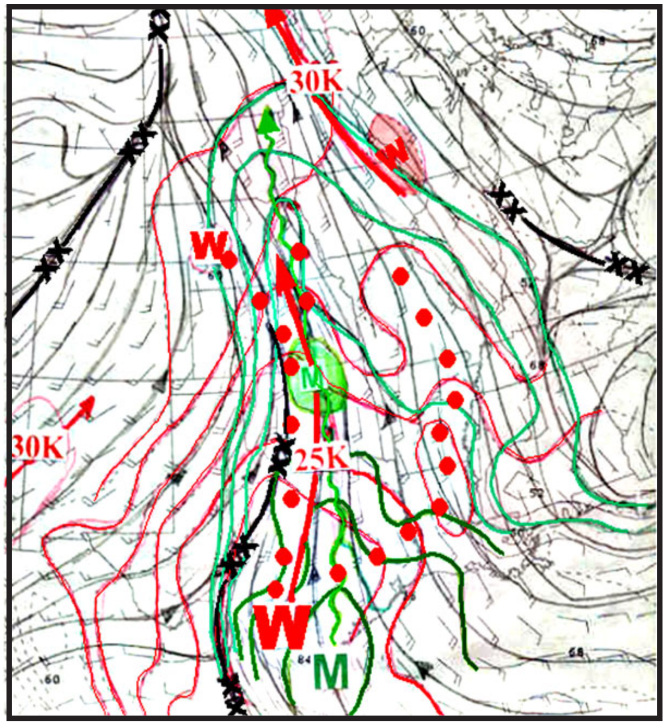

Figure 4-142. 6HR BNDRY LYR FCST, 1800Z/3 May 1999.

Figures 4-143 and 4-144 depict late afternoon visible pictures of supercell and tornadic thunderstorms over the central and southern Great Plains. (Satellite images courtesy of NOAA/NESDIS archive.)

Severe weather reports received at the Air Force Weather Agency (AFWA) Severe Weather Unit for the May 3 outbreak are shown in Figure 4-145. Tornado reports totaled 76, along with 75 hail reports.

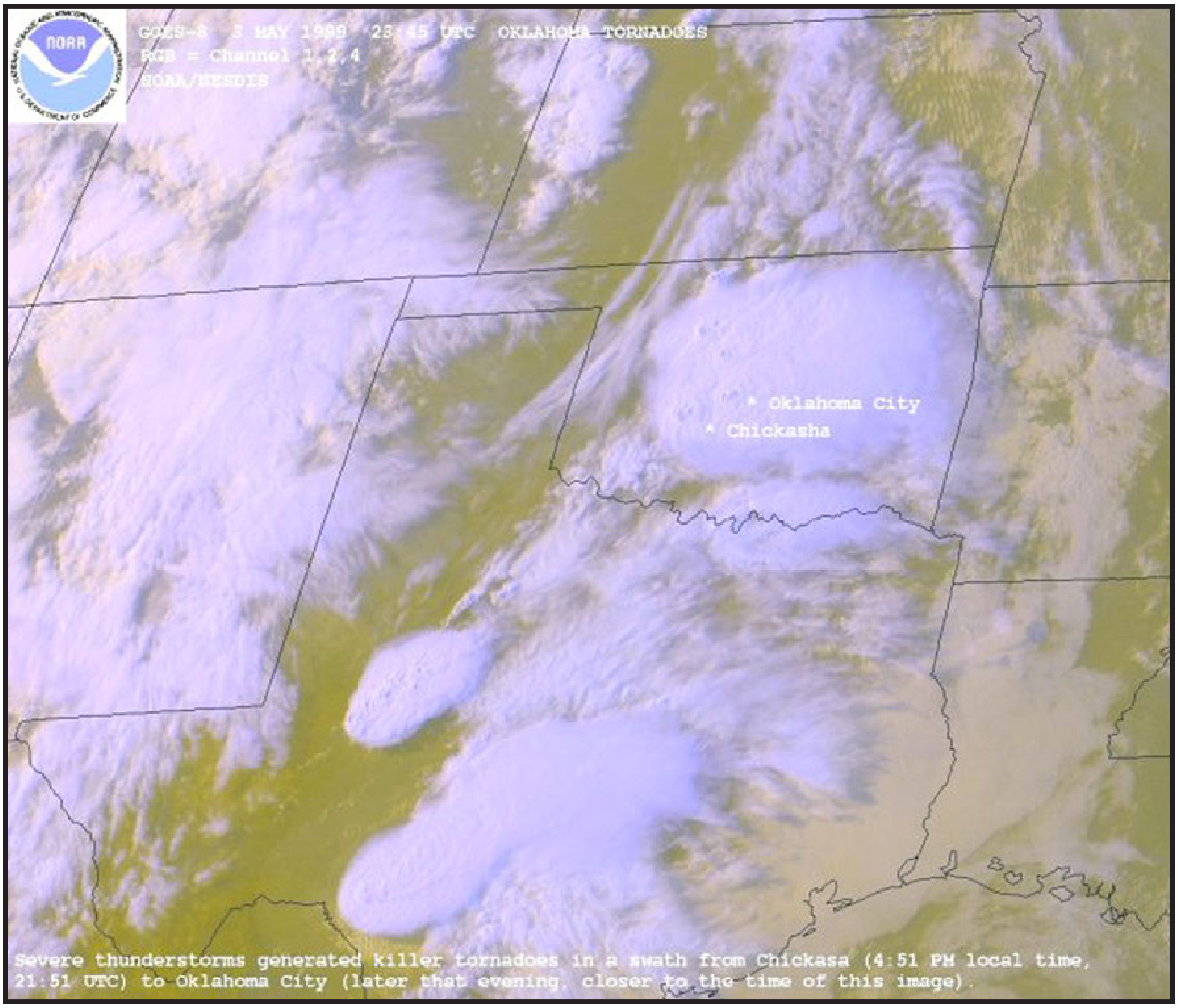

Figure 4-143. GOES E VIS, 2345Z/3 May 1999

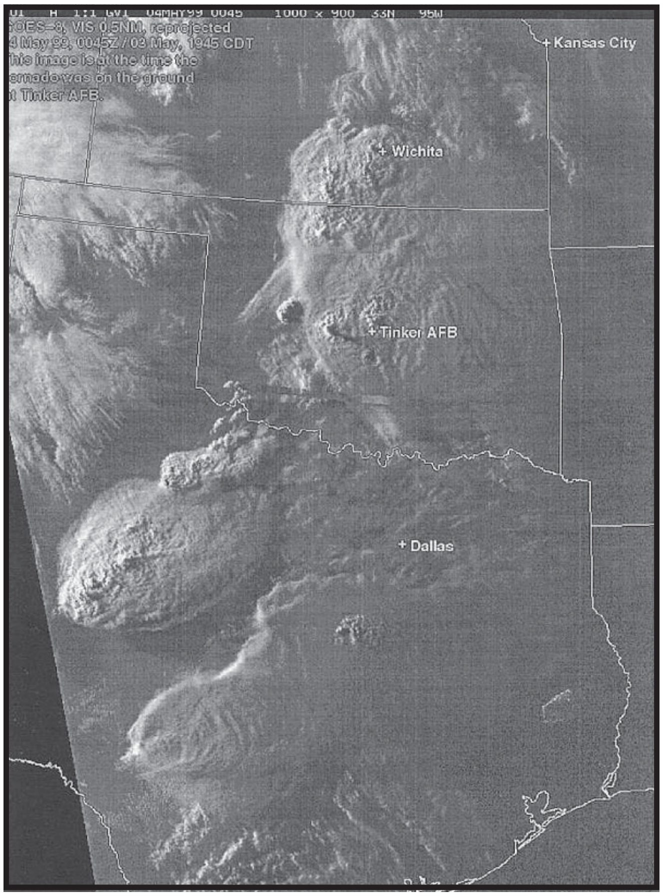

Figure 4-144. GOES E VIS, 0045Z/4 May 1999. This image is at the time a tornado was on the ground at Tinker AFB.

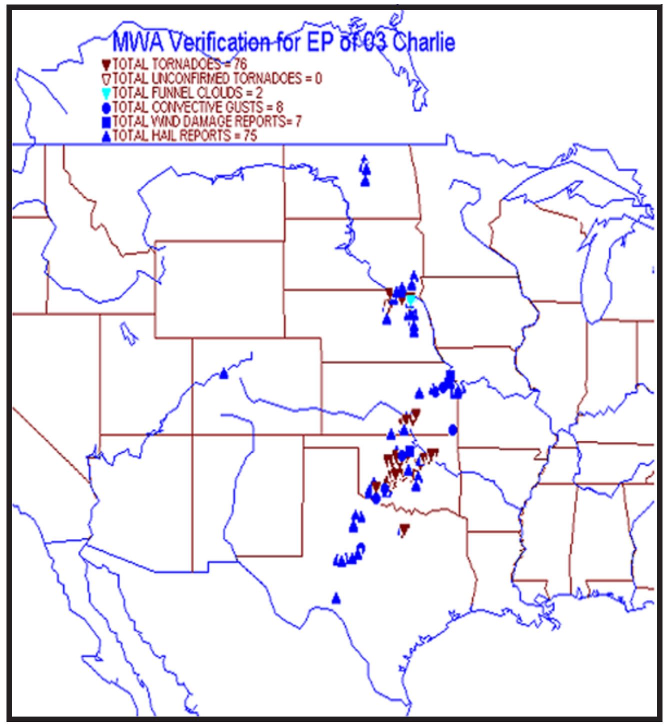

Figure 4-145. Severe Convective Reports, 1600Z/ 3 May to 0600Z/4 May 1999. Courtesy AFWA's Severe Weather Unit

Example 5, Dry Line Convergence, 4 June 2001

Figures 4-146 through 4-147 illustrate another dry line event.

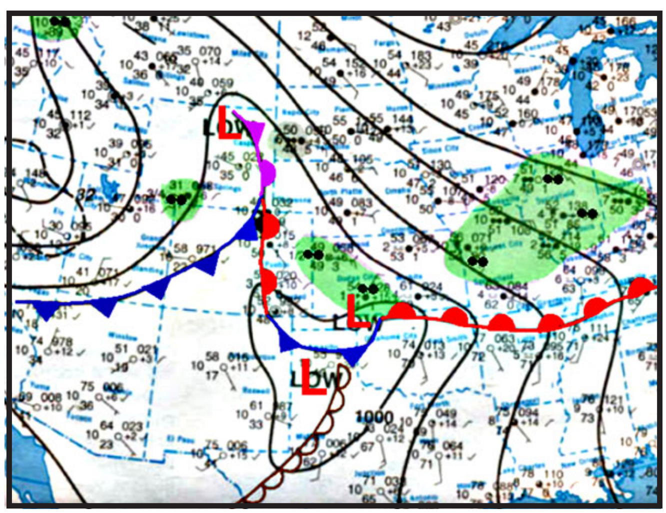

Figure 4-146. Surface, 1200Z/4 June 2001

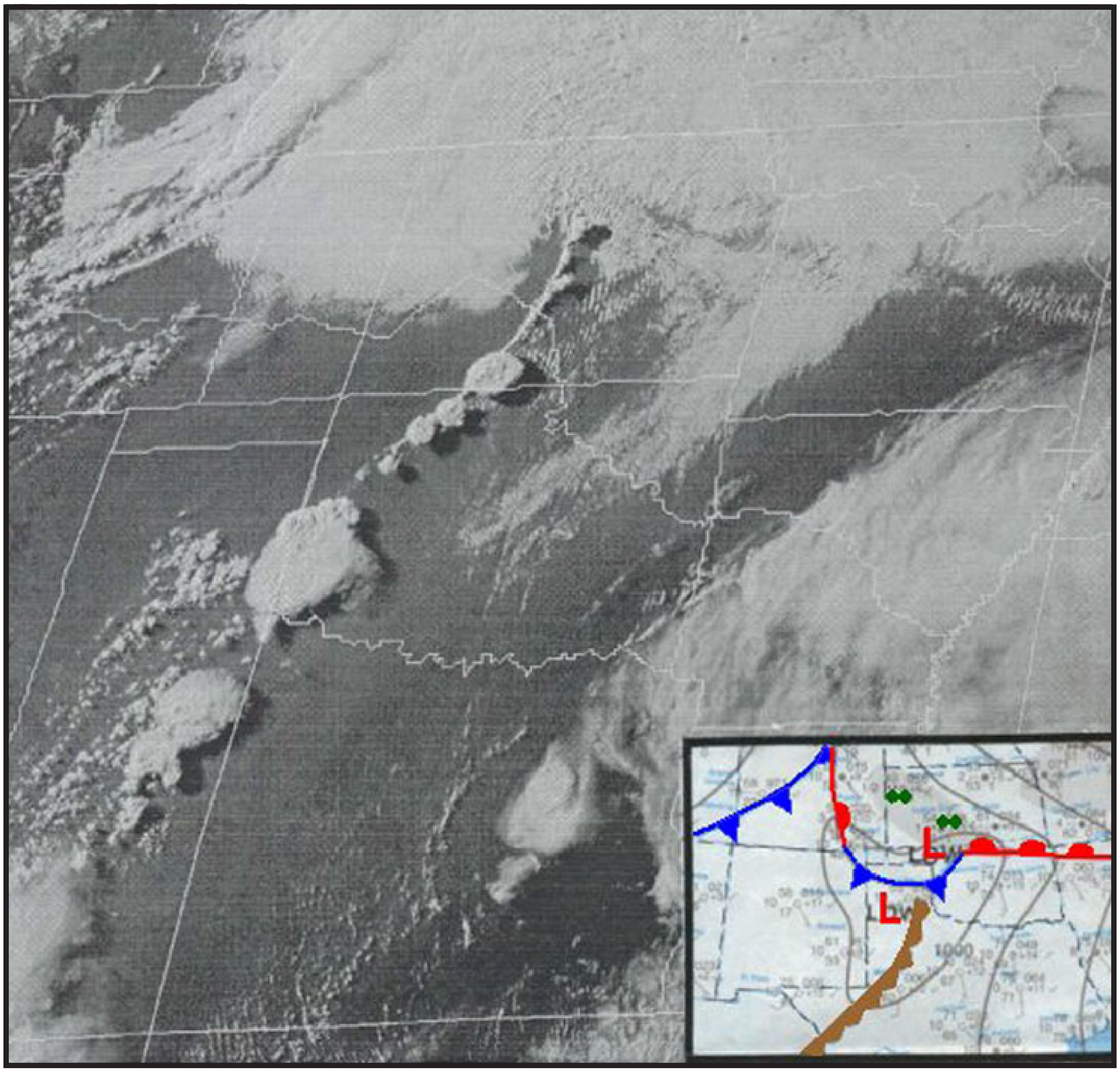

Figure 4-147. GOES E VIS, 2345Z/4 June 2001. INSET: Surface, 1200Z/4 June 2001 (same as Figure 4-146).

Example 6, Dry Line Convergence, 18 April 2002

Another classic dry line example is depicted in Figure 4-148. In this example, the dry line separates 70° dew points on the east side from 20° dew points on the west side. Convergence is evident across the dry line. Thunderstorms broke out east of the dry line as shown in the inset. Severe thunderstorm watch boxes are noted in the inset.

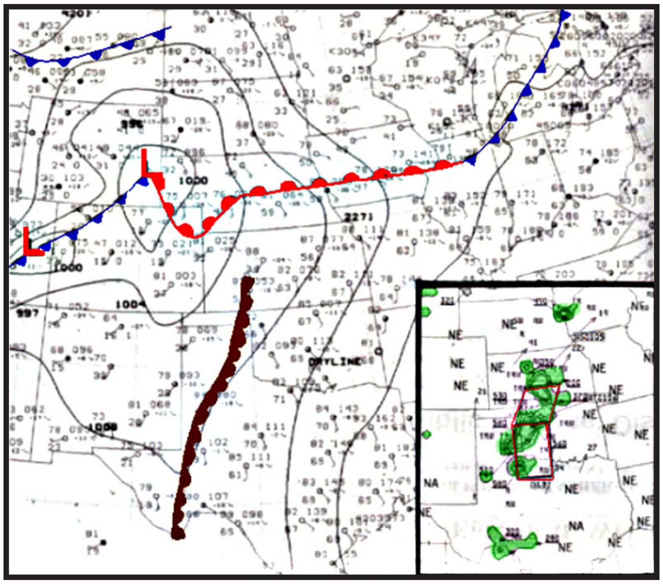

Figure 4-148. Surface, 0000Z/18 April 2002. INSET: Radar Summary, 0115Z/18 April 2002

Rocky Mountain Convergence

Convection over the Rocky Mountains begins during May and continues throughout the summer months. Generally during spring, convection is associated with mP cold fronts that have dropped out of the mountains and encounter low-level moisture over the plains of eastern Colorado and Wyoming (Figure 4-149). The Rocky Mountain/western Great Plains thunderstorm regime that will be shown in Figures 4-149 through 4-151 occurs frequently during the summer. Cold frontal passages being infrequent during summer, convection generally moves eastward into the Great Plains associated with short waves or other minor impulses. During spring, however, mP cold fronts and the dry line generate most convection. (Occasionally the dry line will shift westward and lie along the leeward side of the Rocky Mountains).

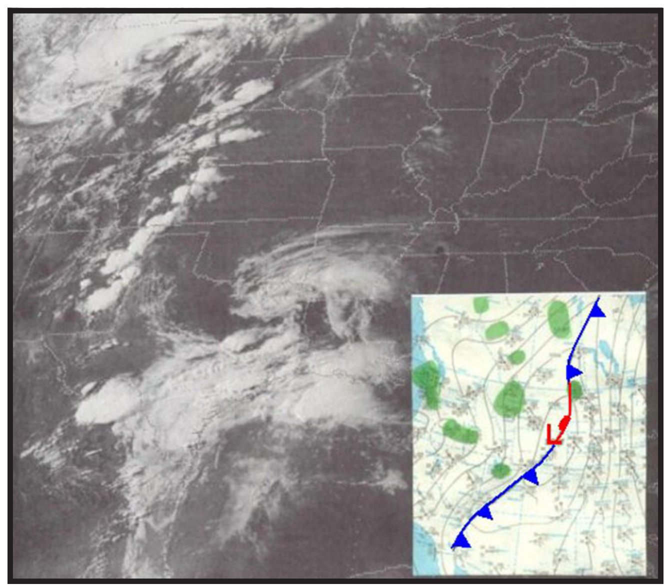

Figure 4-149. GOES E VIS, 2230Z/09 May 1983. The inset shows the surface conditions at 1200Z (approximately 10 hours earlier than the satellite image). A cold front has moved into western Wyoming and Colorado.

Figure 4-150 and figure sequence 4-151a through 4-151d depict convection that begins over the Rocky Mountain and intensifies rapidly when the line moves into a rich low-level moisture source east of the mountains.

Convergence Zone Convection

It was mentioned earlier that outflow boundaries left over from nocturnal thunderstorm activity, weak frontal zones that may not be apparent on analyses, convergence zones in the wind fields, and upper cold troughs or combinations of the above may produce thunderstorm events. Continuity on old stationary fronts that have weakened to the extent that they may be difficult to locate on surface and/or boundary layer charts must be followed. Convection may develop quickly along these old boundaries when the air mass is moist and highly unstable. Several examples follow:

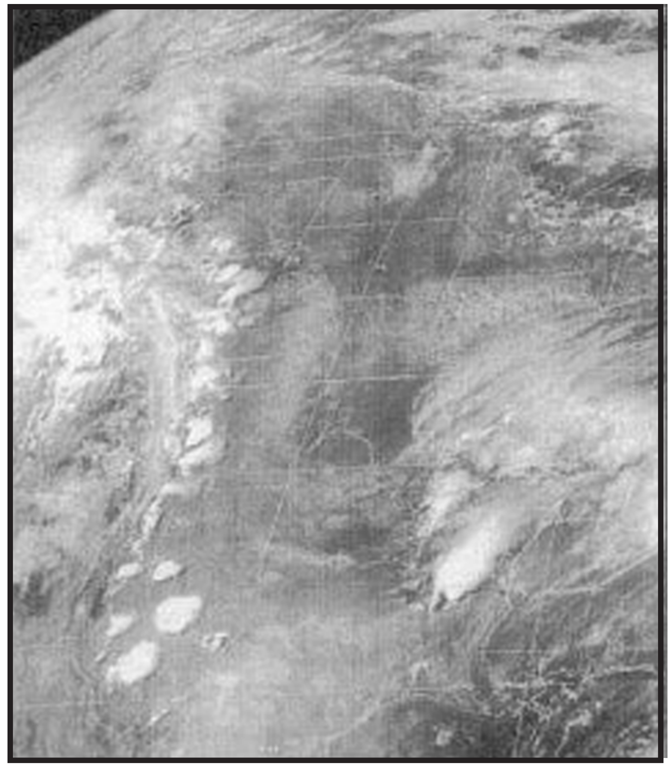

Figure 4-151a. GOES E VIS, 2132Z/26 May 1998.

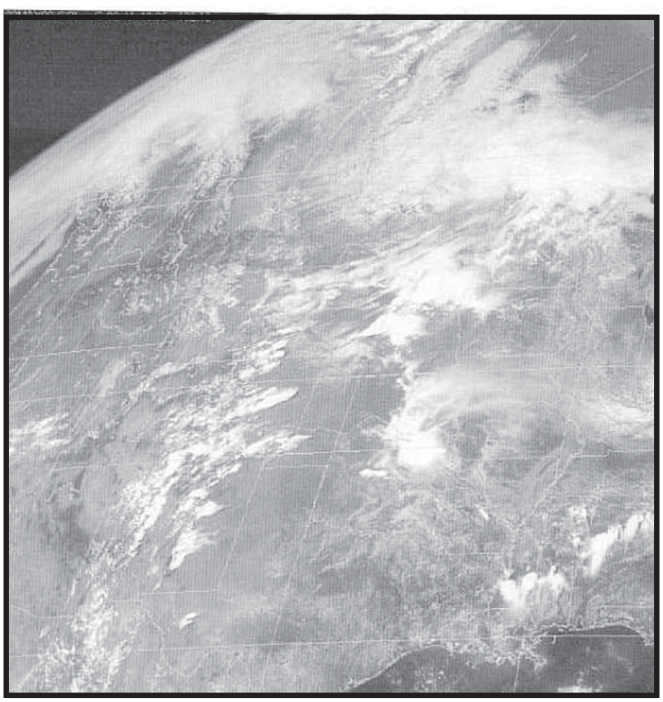

Figure 4-150. GOES E VIS, 1932Z/22 May 1999. Line of convection has developed east of the Rockies.

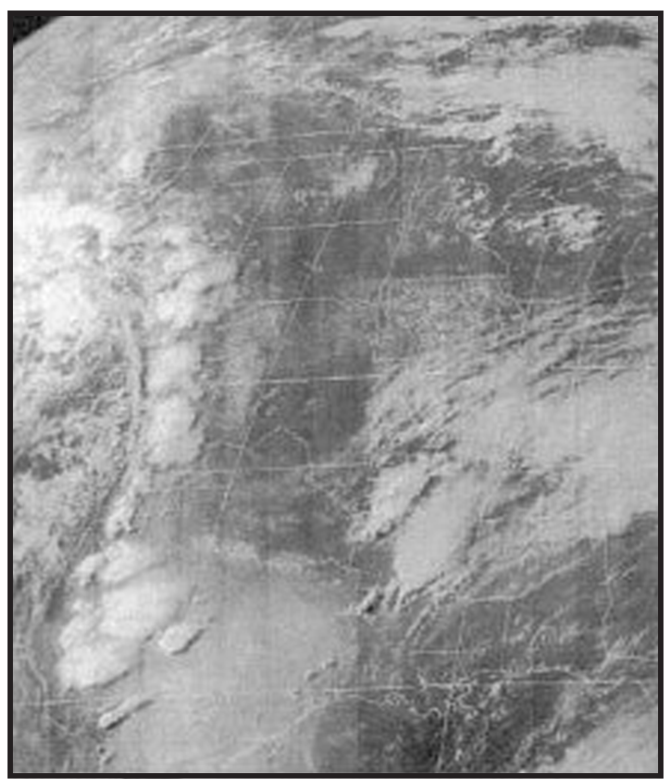

Figure 4-151b. GOES E VIS, 2302Z/26 May 1998.

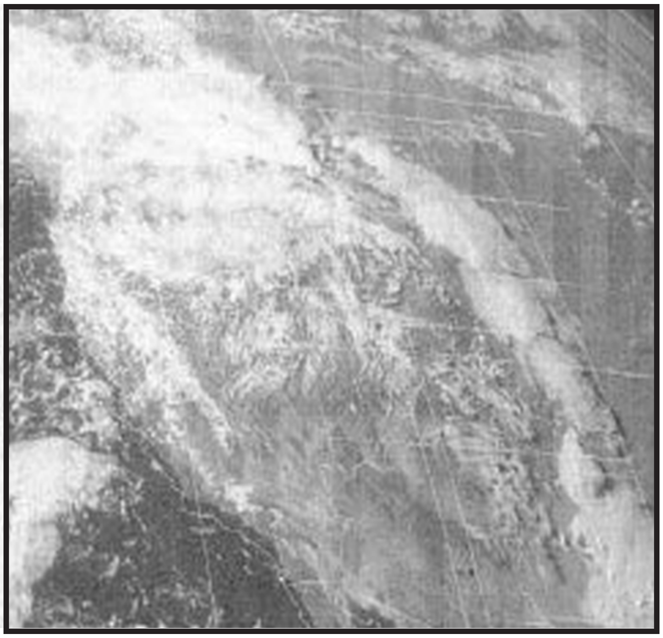

Figure 4-151c. GOES W VIS, 0040Z/27 May 1998. A GOES West view of the Rocky Mountain event

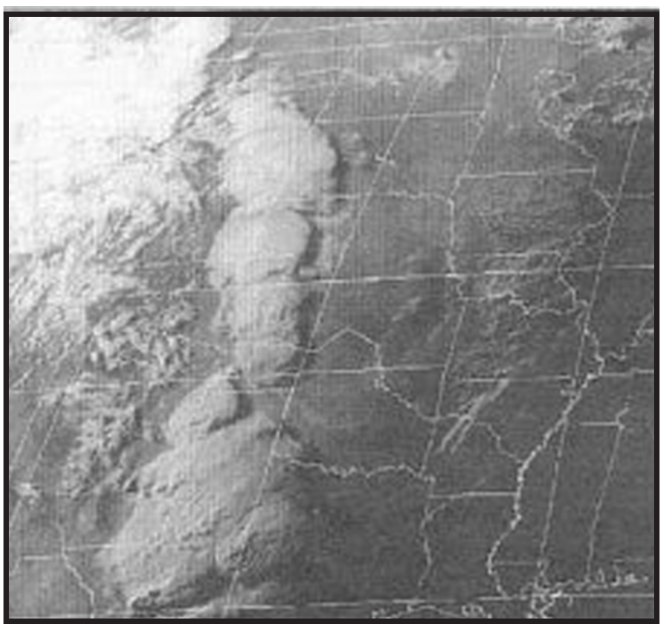

Figure 4-151d. GOES E VIS, 0102Z/27 May 1998.

Example 1 – 29 May 1982

In Figure 4-152, the arrows mark the potential for convection along a cumulus street/cloudfree boundary. Convection has developed over eastern Missouri and may eventually build westward into Oklahoma. The boundary is likely an old frontal zone associated with the cyclonic circulation over eastern Iowa (no surface data available).

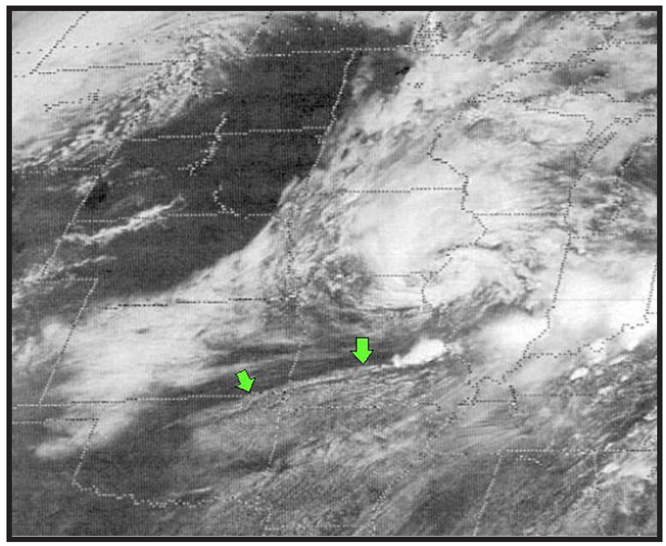

Figure 4-152. GOES E VIS, 1731Z/29 May 1982.

Example 2 – 26 April 1984

Figures 4-153 and 4-154 depict the development of convection along a cloud/no cloud zone over Iowa, eastern Nebraska and Kansas. In the early morning photo, Figure 4-153, arrows mark the boundary. Some narrow cumulus enhancement is noted over Kansas. Eight hours later, Figure 4-154, the late afternoon photo reveals that thunderstorm cells had developed all along the boundary shown in the morning photo (Figure 4-153).

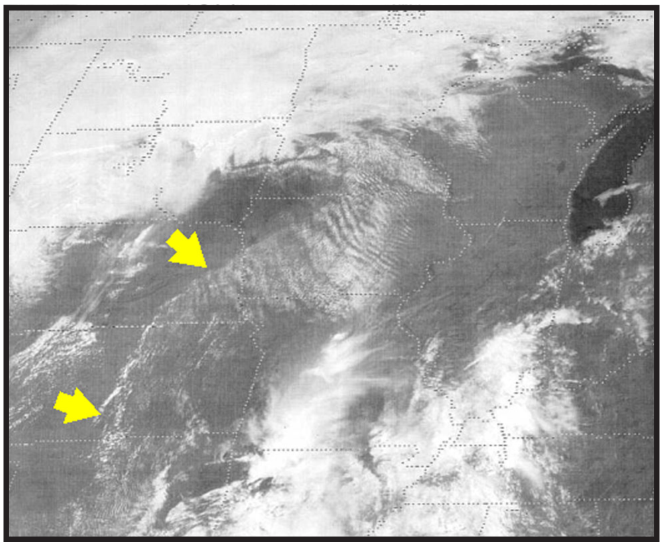

Figure 4-153. GOES E VIS, 1330Z/26 April 1984.

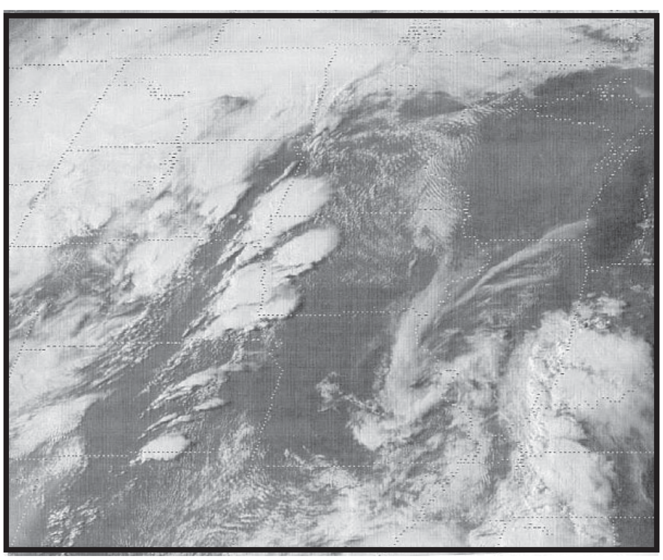

Figure 4-154. GOES E VIS, 2130Z/26 April 1984. Eight hours later from Figure 4-153.

Example 3 - 9 May 2001

In this example, thunderstorms developed along a surface trough as shown in Figure 4-156. The 500mb analysis, Figure 4-155, shows a summer-like upper air regime with northwest flow over the developing thunderstorm area. In Figure 4-156, a morning chart, the dew point east of the trough ranged from 50 to 55°, with 30 to 40°dew points west of the trough. The late afternoon satellite image (Figure 4-157) shows strong and severe thunderstorms that developed along the surface trough. Approximately 143 hail, 21 convective gust (≥ 50 knots) and a few wind damage reports were received from North Dakota, Minnesota and Wisconsin southward to western Kansas.

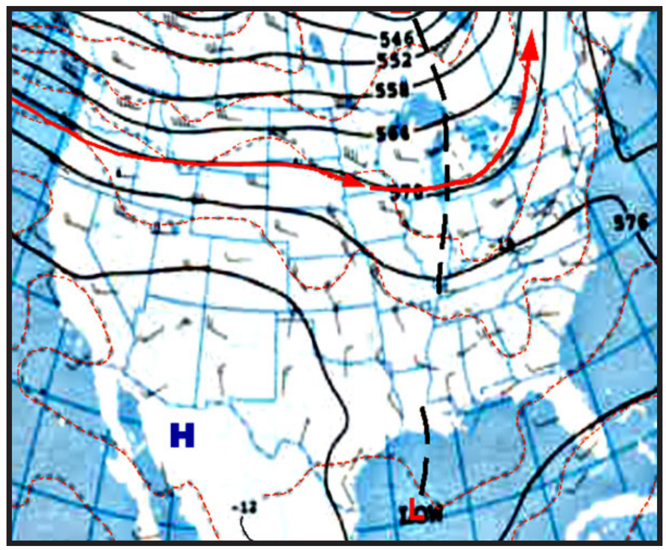

Figure 4-155. 500 mb, 1200Z/9 May 2001.

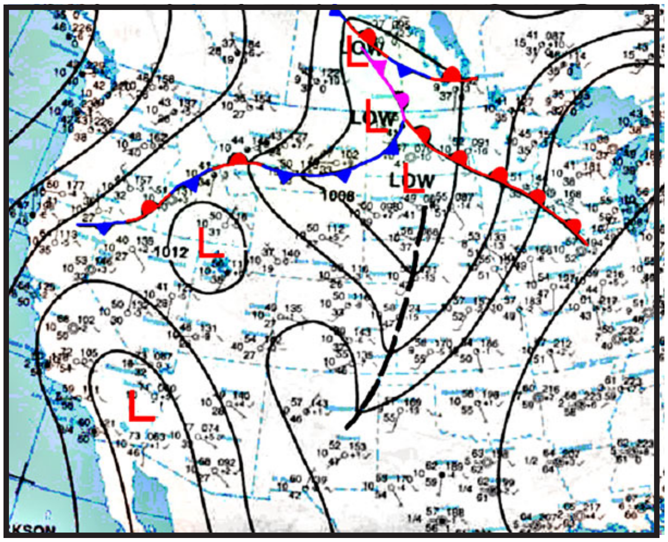

Figure 4-156. Surface, 1200Z/9 May 2001.

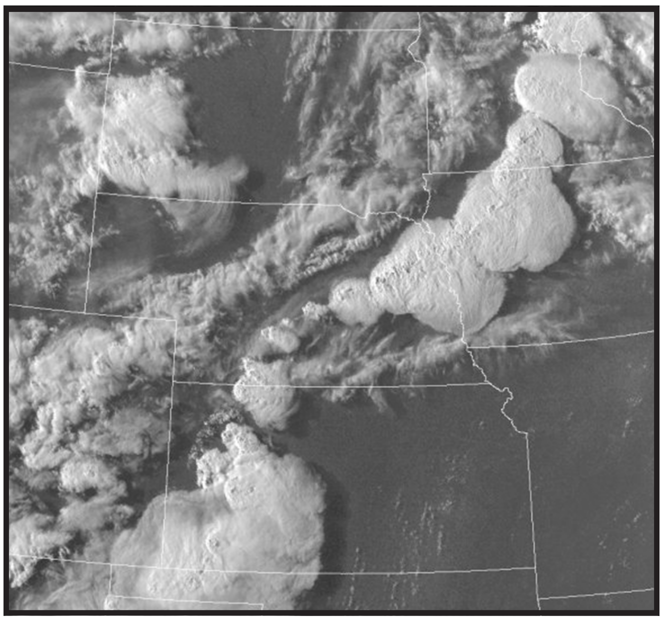

Figure 4-157. GOES E VIS, 2340Z/9 May 2001.

Vorticity Comma Cloud Convection

Vorticity comma cloud systems may produce severe thunderstorm events at any time of the year. During the warm season, however, severe thunderstorms are often associated with this regime. Figure 4-158 shows an early evening IR image over the central plains, of a vorticity comma associated with the large-scale comma system. Approximately 260 severe thunderstorm reports, including tornadoes, were reported. Figure 4-159 shows selected tornado reports for this event.

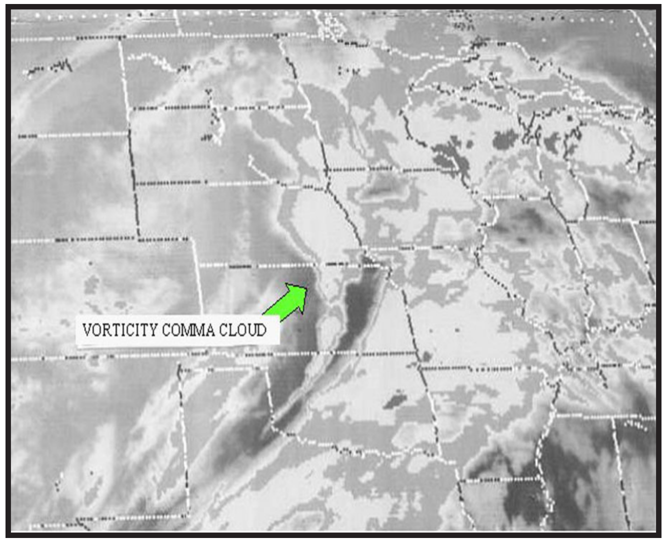

Figure 4-158. GOES E IR, 0345Z/14 March 1990.

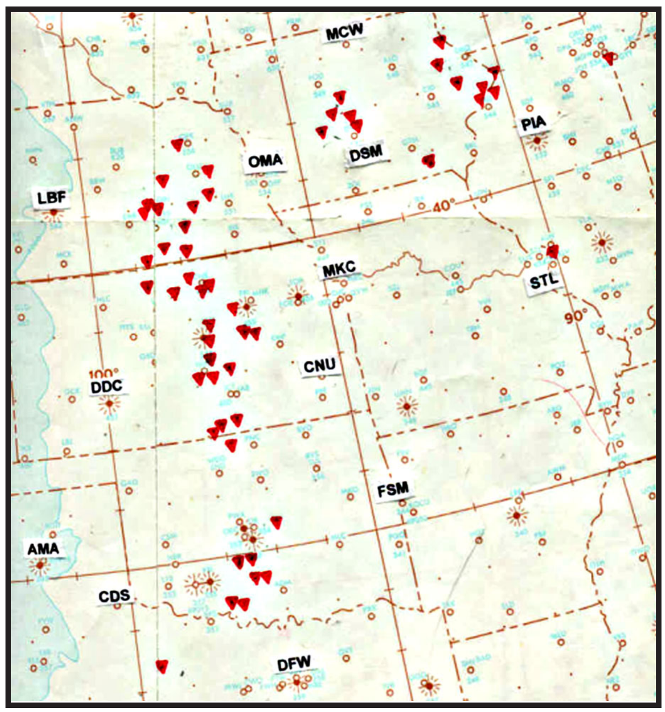

Figure 4-159. Tornado Reports, 13/2100Z to 14/0300Z/March 1990. The reports shown were selected to show the aerial coverage of this event. Ninety-five tornado reports were received; therefore, all reports could not be plotted due to saturation.

Colorado Lows that are born over the Rocky Mountains may mature as they lift slowly northward over the Great Plains due to blocking actions. It was presented earlier that the regime of blocking highs and cutoff lows appears during spring. Blocking highs to the east will either prevent or slow down the normal eastward progression of these lows. Forecasters should be aware that these decaying occluded systems often produce severe thunderstorm events when secondary, smaller-scale PVA systems interact with these large comma systems. The following examples shown in Figures 4-160 and 4-161 depict positive vorticity thunderstorm systems (noted by the arrows) that are associated with mature occluded lows over the Great Plains. Severe thunderstorms and tornadoes are likely especially during the warm, moist, unstable air masses of May when this regime occurs.

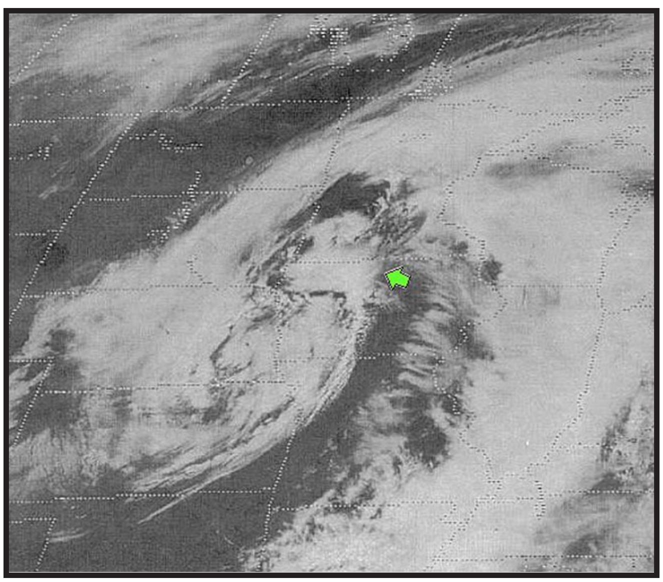

Figure 4-160. GOES E VIS, 1800Z/29 March 1981. Severe thunderstorms are associated with this vorticity system as noted by the arrow.

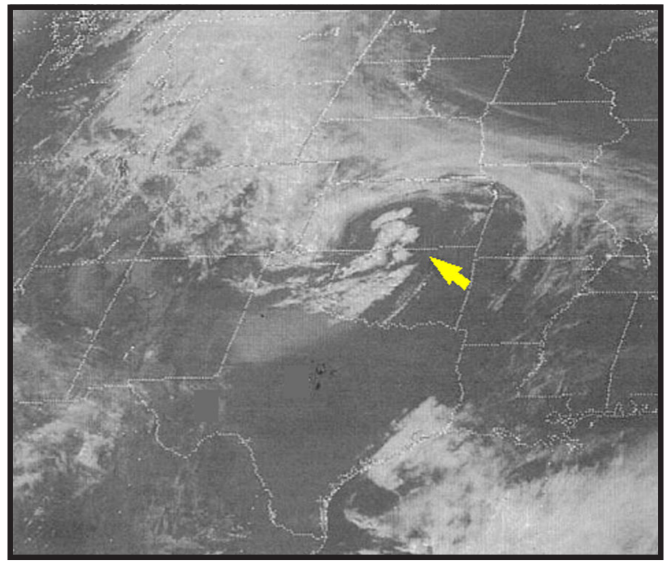

Figure 4-161. GOES E VIS, 2130Z 17 March 1981. Thunderstorms are shown over central Kansas and Oklahoma. A dust swath can be seen over the Texas Panhandle (light gray).

A May example is shown in Figures 4-162 through 4-164. A widespread severe thunderstorm and tornado event occurred as illustrated in Figure 4-164. The morning 500-mb heights/vorticity analysis shown in Figure 4-162 depicts a stagnant low over the northern Great Plains, that is nearly barotropic, as indicated by the nearly coincident vorticity isopleths/height contours. A strong PVA lobe system is shown over the southern plains. This lobe lifted northeastward into Missouri and Iowa later in the afternoon where the air mass was moist and highly unstable. The early afternoon photo, Figure 4-163, shows that widespread thunderstorms have developed from Missouri to Wisconsin and the cloud system has taken on the appearance of a comma as noted by the arrow. The mature large-scale system can still be seen in parts over the Great Plains. The deformation zone can be identified over the upper Mississippi Valley. Figure 4-164 depicts selected severe thunderstorm and tornado reports for a twelve-hour period. Approximately one-third of the reports were plotted. As can be seen, this was a major tornado outbreak in May.

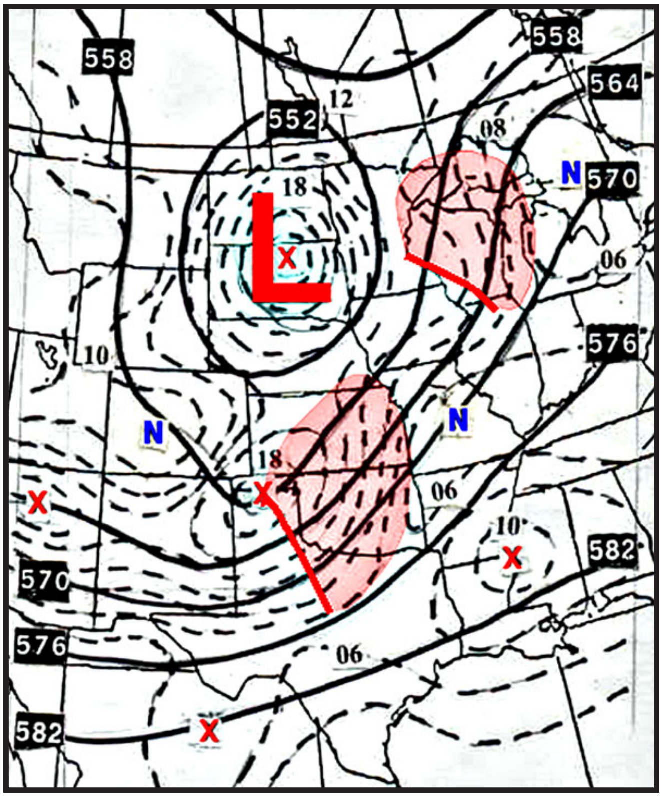

Figure 4-162. 500MB HEIGHTS/VORTICITY, 1200Z/8 May 1988.

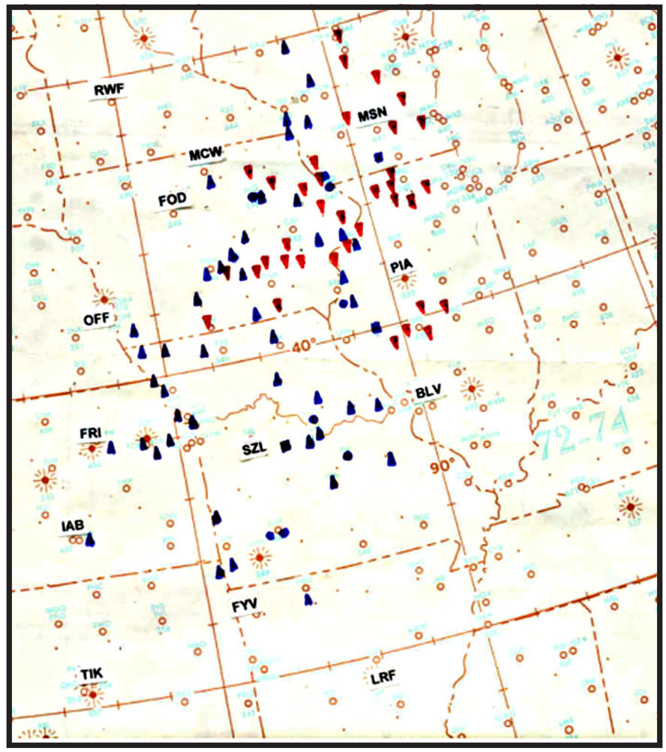

Figure 4-164. Severe Thunderstorm Reports, 1200Z to 0000Z/8-9 May 1988.

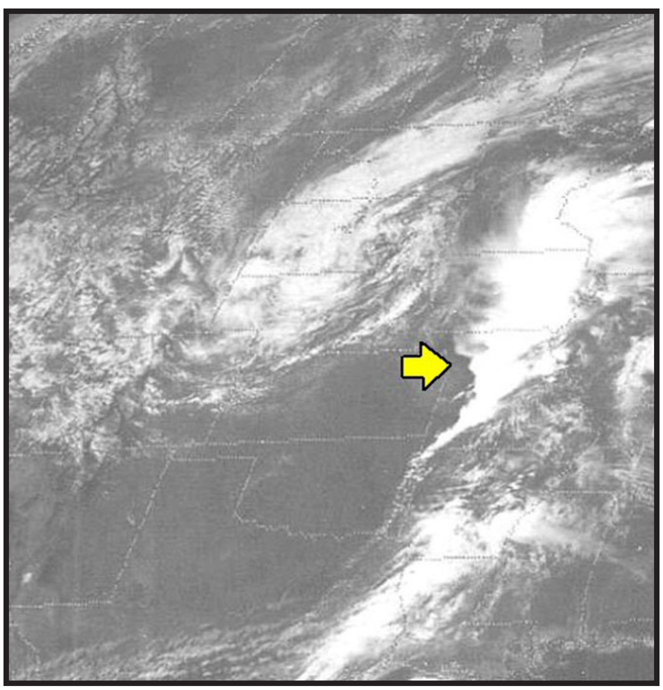

Figure 4-163. GOES E VIS, 1958Z/8 May 1988. A disorganized large-scale comma covers most of the central CONUS.

Cold Air Enhanced Cumulus/Low-Top Cumulonimbus

During April and early May, enhanced cold air cumulus and/or lower top cumulonimbus cells may occur over land areas during the heating hours when sufficient moisture is available. Enhanced cumulus areas, located well to the rear of a shortwave comma cloud system, often reflect either the major trough position or the presence of a new vorticity center within the cold air of the trough system. In Figure 4-165, a short wave comma cloud system is shown over the eastern CONUS. The related 500mb analysis, Figure 4-166, depicts a strong thermal trough over the central Great Plains. In Figure 4-165, the enhanced cumulus area has developed within the cold air pocket of the major trough line shown in Figure 4-166. Upper air soundings would be an excellent forecast tool to determine if steep lapse rates exist for development of enhanced cold air cumulus. Another excellent tool is the total-totals (analysis and forecasts). Cold air thunderstorm events are generally below the

severe thunderstorm threshold (< ¾” hail and <50 knots). The convective activity diminishes with loss of surface heating. These cold air cumulus events occur frequently over the ocean areas. The Pacific Northwest coastal areas are often affected by enhanced cumulus and low-top cumulonimbus during early spring.

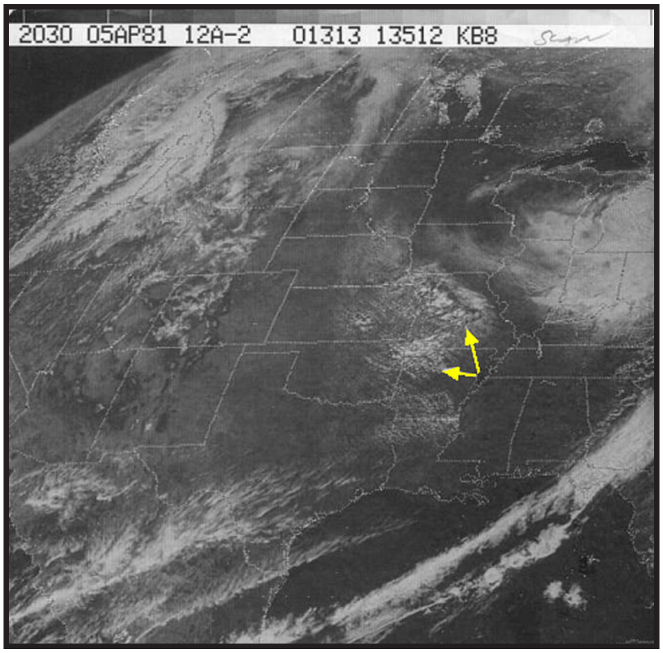

Figure 4-165. GOES E VIS, 2030Z/5 April 1981. The arrows note cold air cumulus and some low-top cumulonimbus cells.

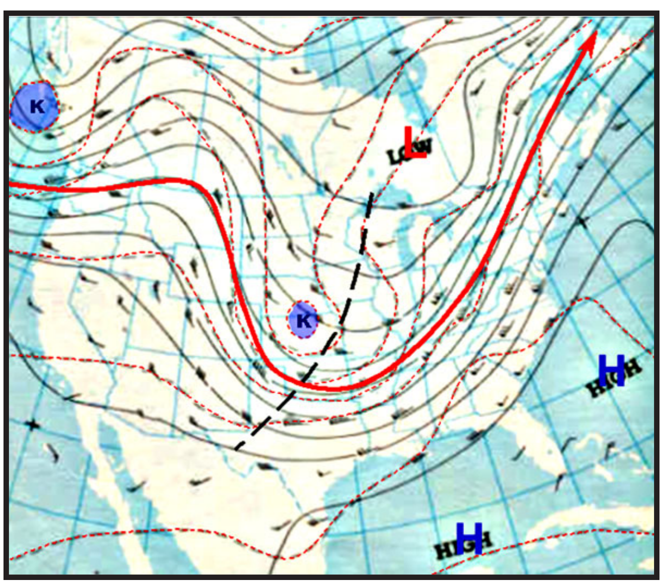

Figure 4-166. 500MB, 1200Z/5 April 1981.

Mesoscale Convective Complexes/Systems (MCC/MCS)

Organized, persistent areas of deep convection are visible on satellite photos during the warm season, especially over the central areas of the CONUS. This regime is primarily a summer event but may occur as early as May, as shown in Figure 4-167. Abundant low-level moisture, strong instability and surface heating are the ingredients for development of these large thunderstorm systems. They typically form during the afternoon and early evening as individual cells; it’s during this time the potential for severe thunderstorms is greatest. These systems continue to grow throughout the nighttime hours producing numerous thunderstorms and heavy rainfall over a given area (Gusty surface winds < 50 knots and small hail may occur). They are often slow-moving due to light steering winds. Many mature systems reveal strong cirrus outflows that indicate a divergent area aloft, as illustrated in Figure 4-167. *(See Summer Regimes for a more detailed discussion on this convective regime).*

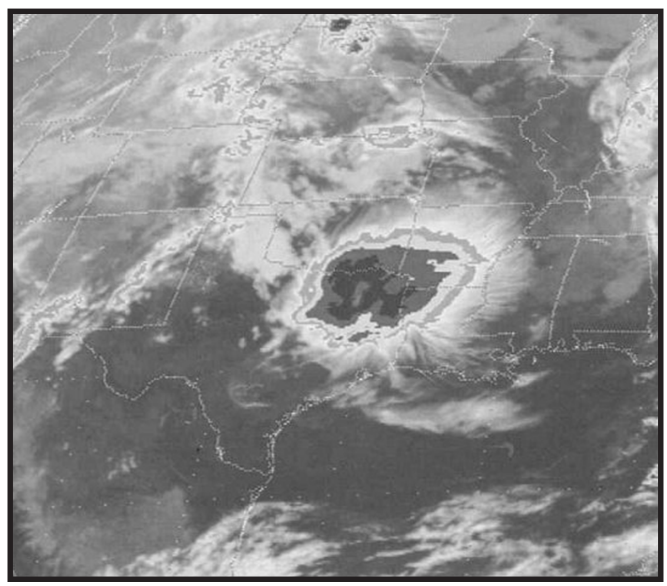

Figure 4-167. GOES E IR (MB Curve), 1300Z/27 May 1981. MCC appears over the southern Plains/ lower Mississippi Valley region in this early morning photo. Strong cirrus outflows indicate the divergent area aloft.

Land/Sea Breeze Convection

This regime is primarily a summer event along the gulf coastal states but may begin in mid to late May. (Chapter Five shows examples of sea breeze activity over Florida).

Tropical Storms

Officially, the Atlantic tropical storm season begins on 1 June. The first tropical storm system within the Gulf of Mexico in 2001 (Allison) formed in early June off of the Louisiana and Texas coast as shown in Figures 4-168 and 4-169. Allison dumped heavy rainfall over southeastern Texas and southern Louisiana as it tracked northward.

Non-Convective Surface Wind Regimes (Notorious Wind Boxes)

The northern and central Great Plains experience many days of strong surface winds in March, April and early May. The non-convective surface wind regimes of winter (*Notorious Wind Boxes*) are included because they will appear in March and April.

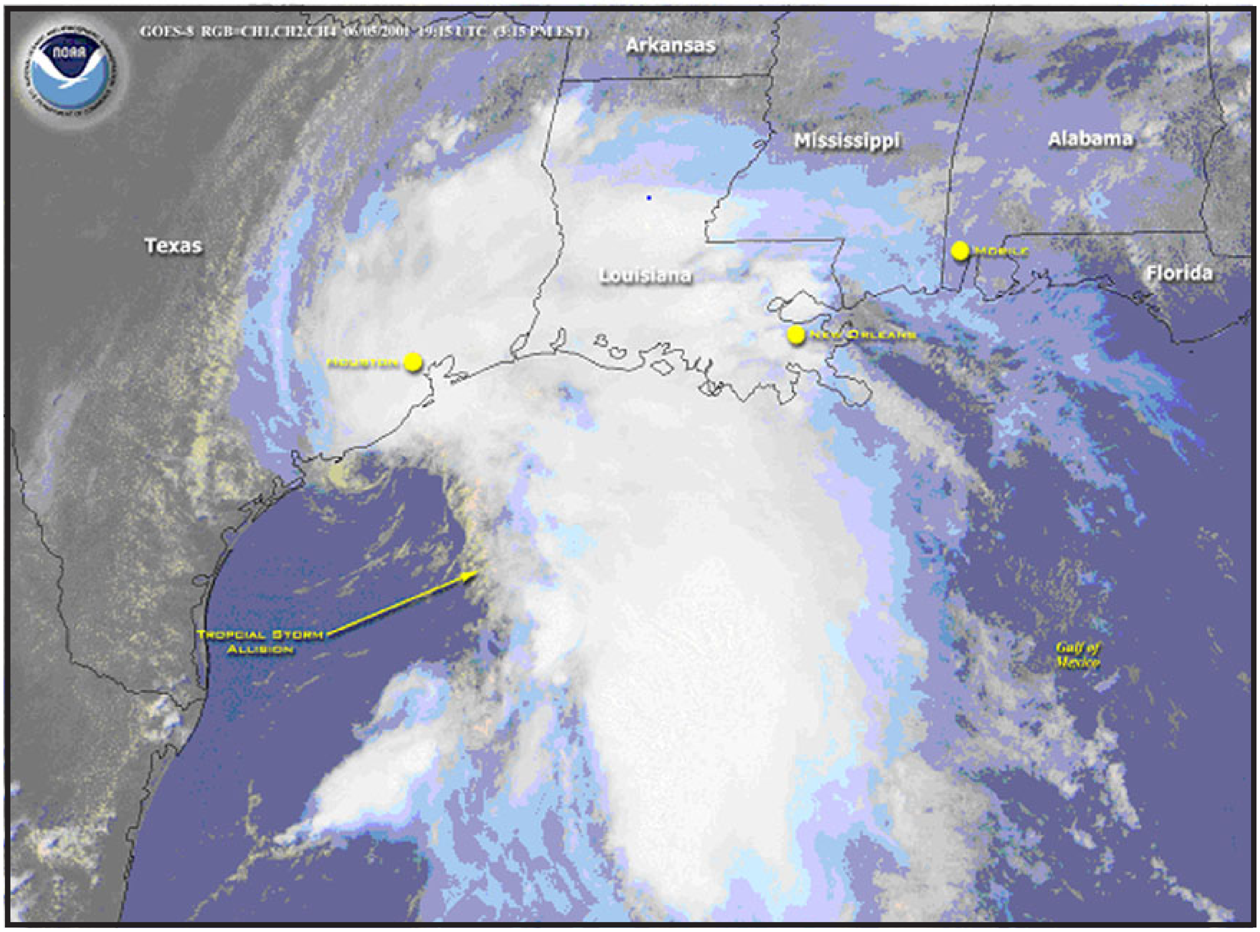

Figure 4-168. GOES-8 RGB=CH 1,CH 2, CH 4, 1915Z/5 June 2001. Tropical Storm (TS) Allison located offshore and moving northward at 11 knots. Estimated sustained winds 50 knots with gusts to 60 knots.

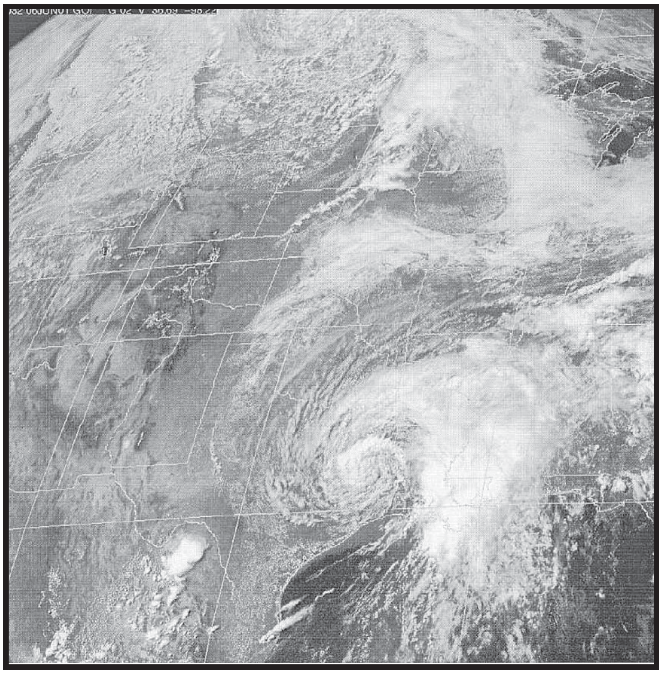

Figure 4-169 GOES E VIS, 2032Z/6 June 2001. Tropical Storm Allison twenty-fours later from Figure 4-168. The storm continued northward and is shown over eastern Texas

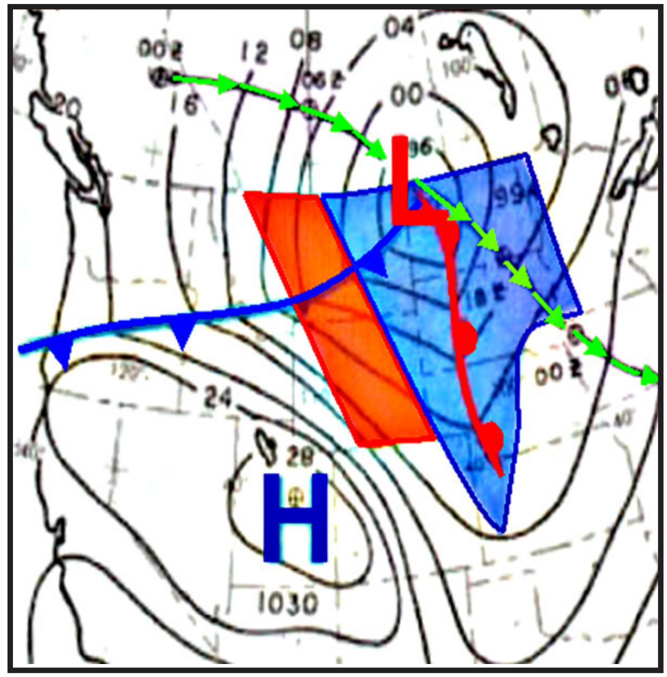

Figure 4-170. Livingston and Northern Great Plains Boxes – Surface. Livingston Box depicted in red. Low-pressure center track shown in green.

Northern Great Plains and Livingston Boxes

The Northern Great Plains wind event shown in Figure 4-170 is primarily a winter regime; however, it may continue into early spring. Southeastward-moving Alberta lows often trigger the Livingston Box and later activate the Northern Plains Box. Because surface wind gusts do not confine themselves to the basic Livingston box as the storm system tracks eastward, this becomes an important storm track. Figure 4-170 depicts a northern Great Plains Alberta low storm track. A typical low-level maximum wind chart is shown in Figure 4-171.

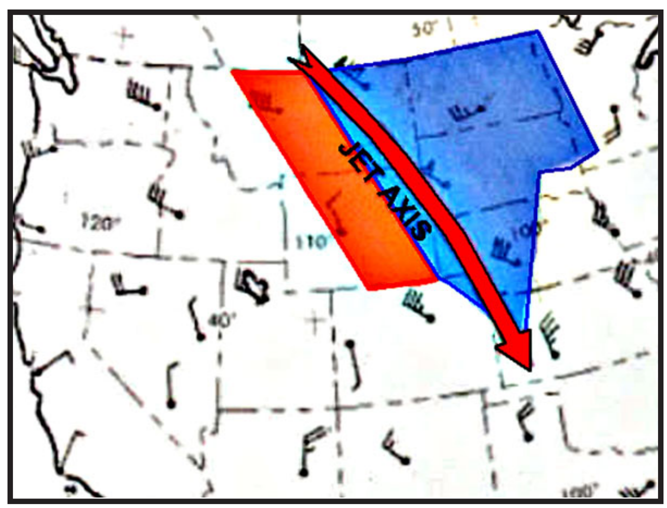

Figure 4-171. Livingston (red) and Northern Great Plains Boxes (blue), Low-Level Maximum Winds

Central Great Plains Box

This wind regime is the most common event during spring across the central CONUS. Pacific mP frontal systems that move out of the Rocky Mountains tighten the surface pressure gradient between the front and the receding ridge to the east. The southerly low-level jet becomes strong and is reflected on the surface by strong southerly winds. Discussions and illustrations on the low-level jet were presented earlier in Figures 4-94 through 4-96. Figures 4-172 and 4-173 illustrate a typical pattern. The initial and forecast boundary layer wind and 850mb charts are tools for predicting the area of strong surface winds. The shaded area in the maximum wind chart, Figure 4-173, depicts the low-level jet.

Figure 4-174 shows strong east-west pressure gradients between a receding high and a Pacific maritime polar cold front, and compares favorably with the model shown in Figure 4-172. A strong low-level jet and surface winds occurred with this regime. This event was presented earlier in Figures 4-98 through 4-104.

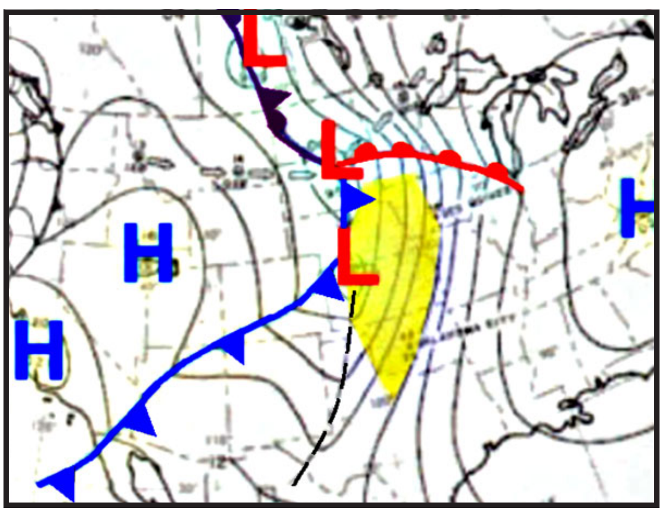

Figure 4-172. Central Plains Box.

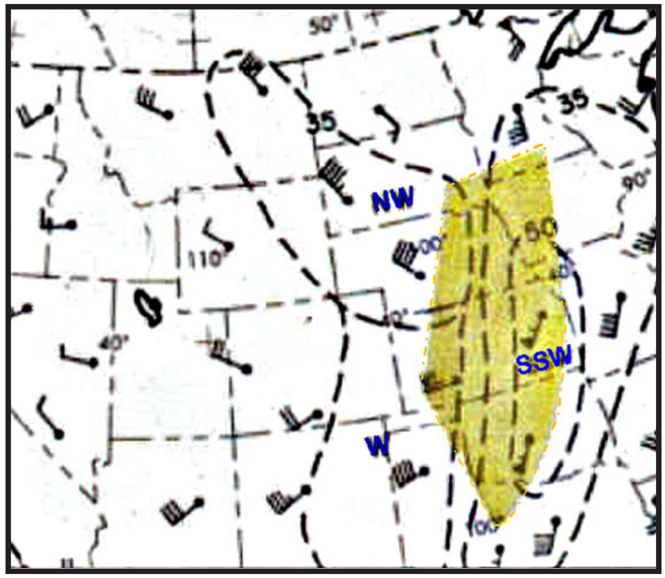

Figure 4-173. Central Plains Box, Low-Level Maximum Winds.

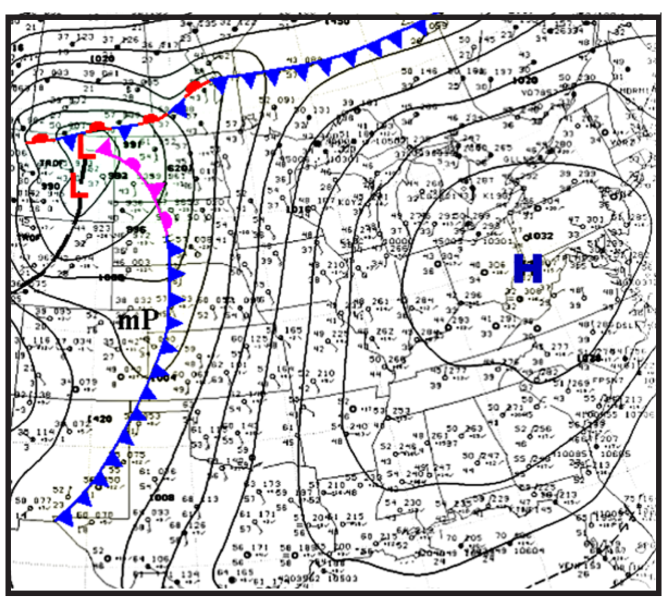

Figure 4-174. Surface, 1200Z/22 May 2002.

Dusty Box

The Dusty Box is primarily a spring regime due to either frequent development of upper level closed lows over southern California/eastern Arizona, or upper lows that dig southward from the Pacific Northwest. These low-latitude systems track across eastern Arizona, New Mexico and into the Texas Panhandle and southeastern Colorado as depicted on Figure 4-175. Tight surface pressure gradients across the mountainous areas of Arizona and New Mexico are not always evident, even though strong westerly winds may be occurring at mid-levels (Figure 4-176). Forecasters may be misled by apparently weak surface gradients into thinking that strong westerly winds will not occur at the surface. Surface heating and orographic influences will mix middle level winds to the surface to produce an outbreak of strong winds.

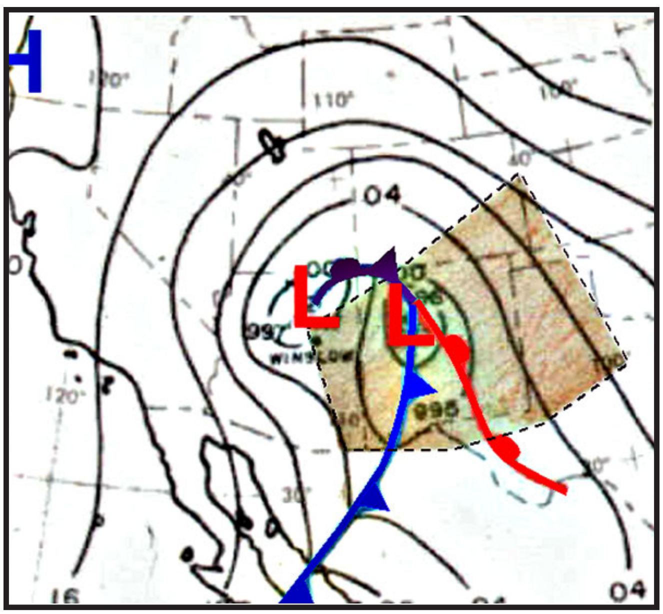

Figure 4-175. Dusty Box.

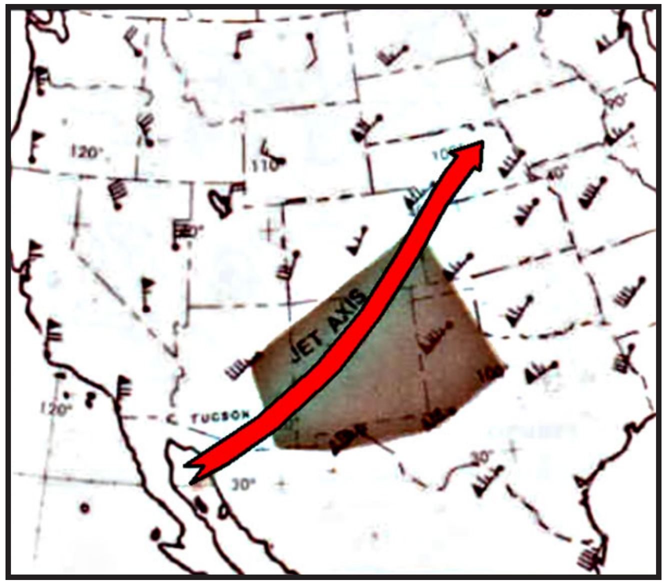

Figure 4-176. Dusty Box, Mid-Level Maximum Winds.

Figures 4-177 and 4-178 show two more dust events across the Texas Panhandle and western Oklahoma in early April.

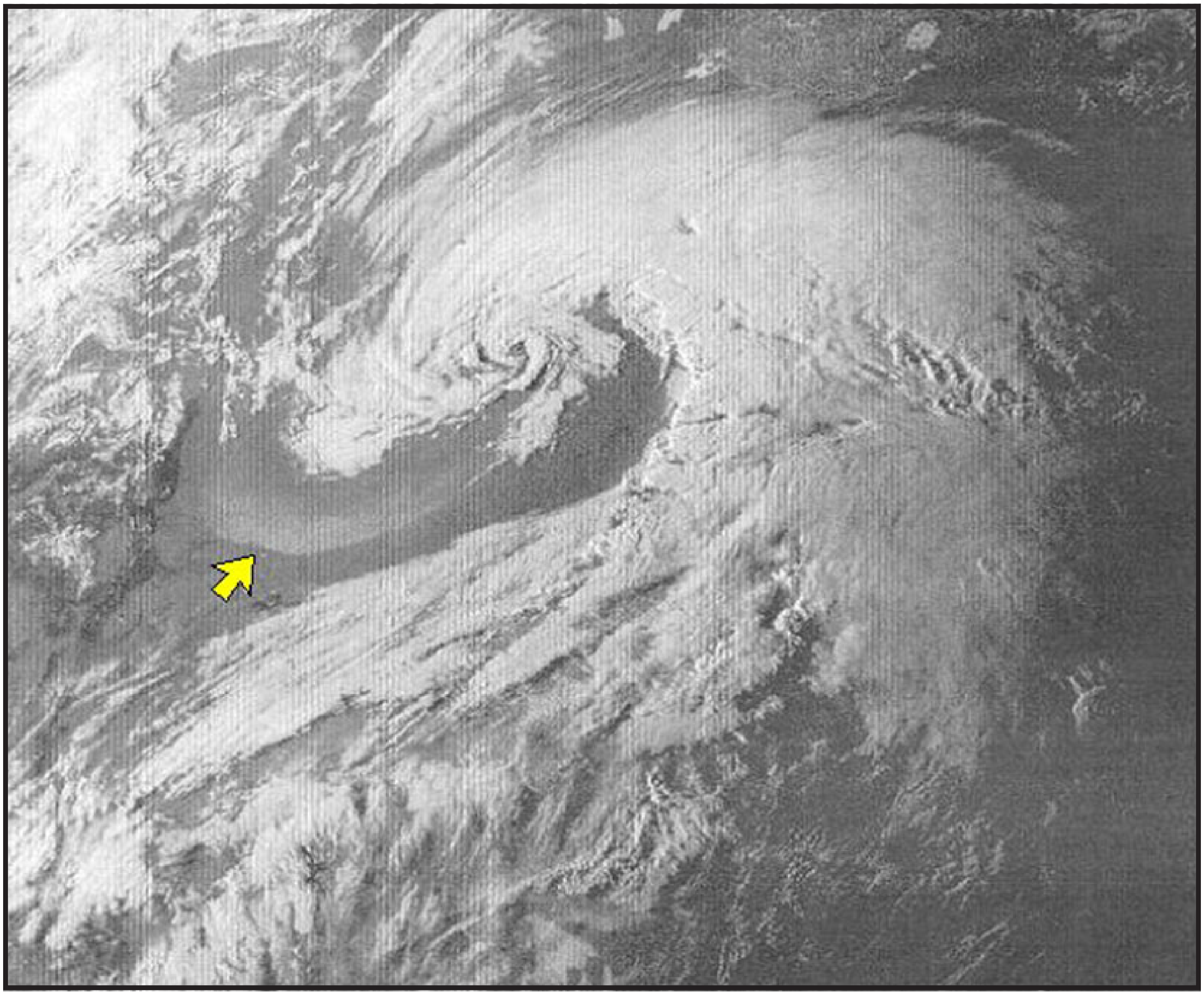

Figure 4-177. GOES E VIS, 2332Z/8 April 1999. A dust swath (arrow) extends across the Texas Panhandle to western Oklahoma.

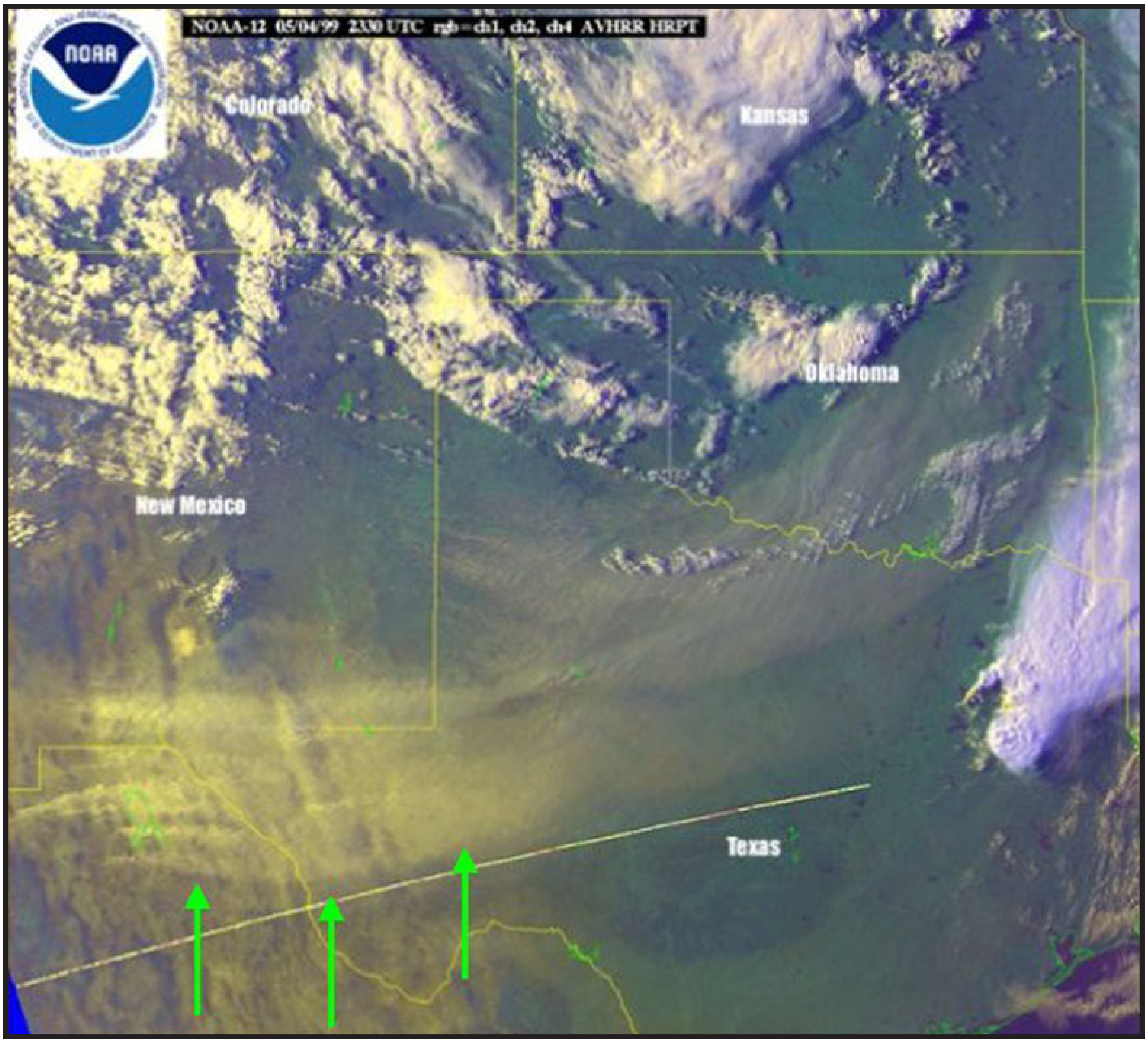

Figure 4-178. NOAA 12, RGB CH 1, CH 2, CH 4, 2130Z/5 April 1999. Green arrows mark a dust swath. *Courtesy NOAA Archive*

EASTERN CONUS

Upper Levels

As presented in the previous chapters, short waves within zonal flow occur across the CONUS during spring. The winter regime of longwave trough/ridge events over the eastern CONUS decreases significantly during spring, as these short waves become the primary regime.

Jet Streams

By mid-spring the polar jet has drifted northward, and by the onset of summer it lies across the northern CONUS and southern Canada. Figures 5-1 through 5-5 illustrate selected jet stream locations from early spring (Figure 5-1) through mid-spring (Figures 5-2 and 5-3) and finally into late spring and early summer (Figures 5-4 and 5-5). By late spring and continuing into summer the subtropical ridge and associated high cells appear over the central and southern CONUS as depicted in Figures 5-4 and 5-5.

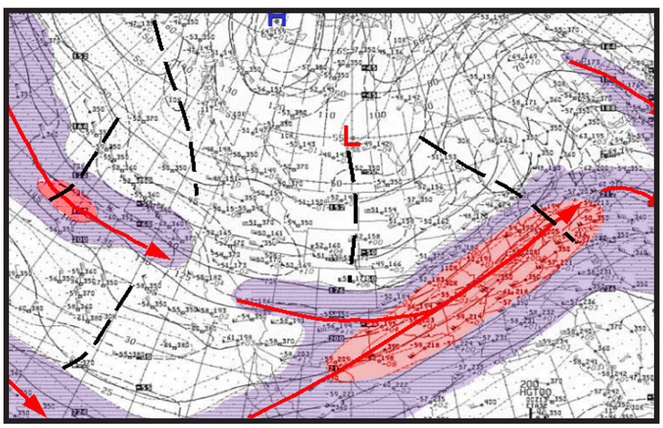

Figure 5-1. 200 mb, 0000Z/13 April 2001. Polar jet is shown across the southern and eastern CONUS.

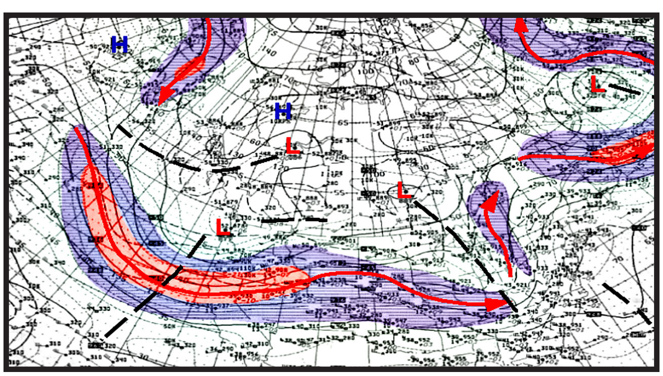

Figure 5-2. 300 mb, 1200Z/10 May 2000. The polar jet generally appears across the central CONUS by the mid-spring.

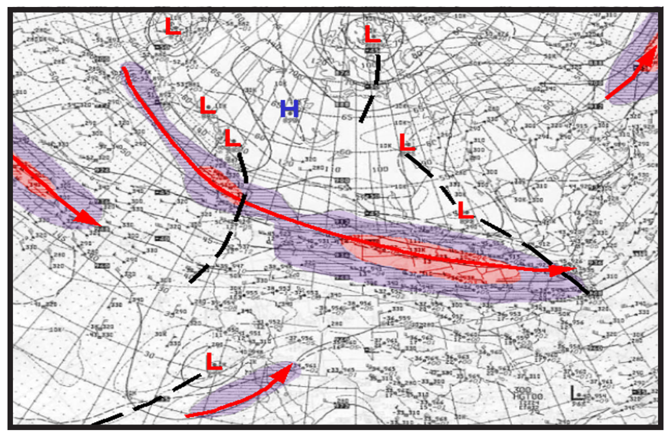

Figure 5-3. 300 mb, 1200Z/24 May 2000.

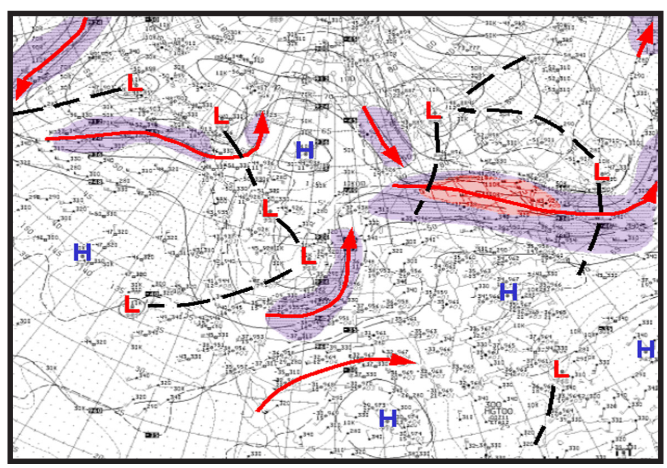

Figure 5-4. 300 mb, 0000Z/11 June 2002. By late spring, the subtropical ridge/associated high cells appear on the scene as noted over southern Texas and the eastern CONUS.

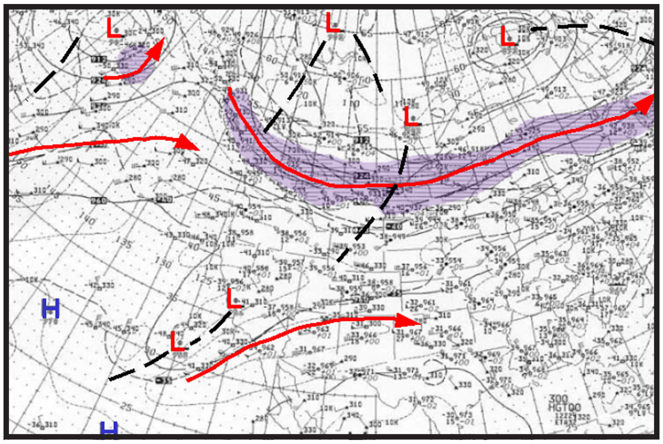

Figure 5-5. 300 mb, 1200Z/24 June 2000. The polar jet is shown over the northern CONUS and southern Canada at the onset of summer.

Shortwave Systems

Figures 5-6 through 5-9 depict various shortwave systems that appear over the eastern CONUS. Short waves' southward extent over the southern CONUS weakens when the subtropical ridge shifts northward as shown in Figures 5-8 and 5-9.

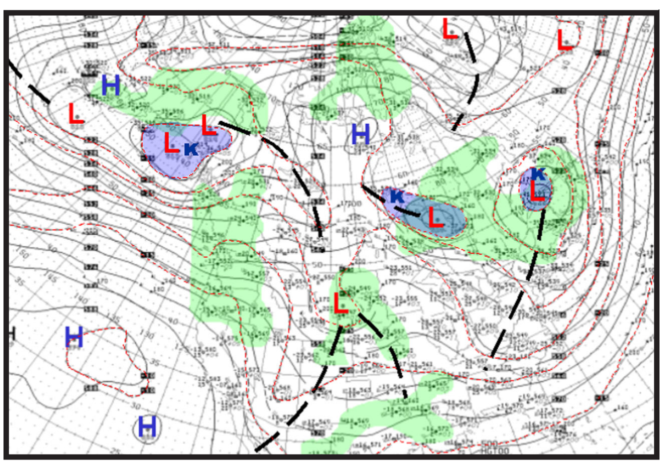

Figure 5-6. 500 mb, 0000Z/28 March 2001.

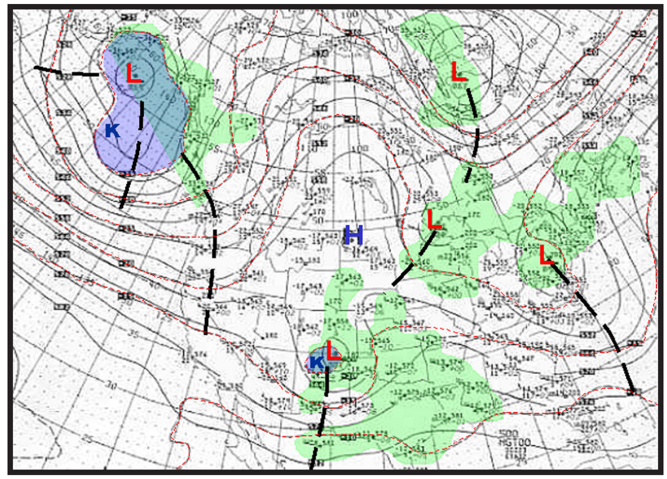

Figure 5-7. 500 mb, 0000Z/23 April 2000.

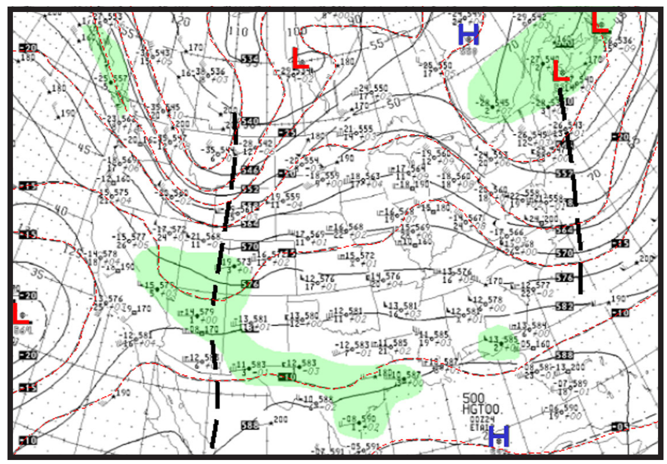

Figure 5-8. 500 mb, 0000Z/24 April 2002. Short waves moving eastward within zonal flow.

Cutoff Lows

Cutoff low and blocking high regimes were presented earlier in Chapter 2 (Some text from Chapter 2 will be repeated here). Cutoff lows do occasionally appear over the eastern CONUS during spring and early summer. Starting in late April and continuing through May, lows sometimes tend to break away from the main westerlies located across the northern CONUS and Canada. Cutoff lows appear more often during the transitional periods of spring and autumn, because the belt of westerlies still lies across the northern CONUS and Canada. Prior to and during the cutoff period, the main jet stream continues to lie to the north, although a weaker jet may appear within the cutoff low circulation.

Cutoff lows may occur over any area of the CONUS at any time of the year. These systems often move slowly, and it is not uncommon for one to appear continuously

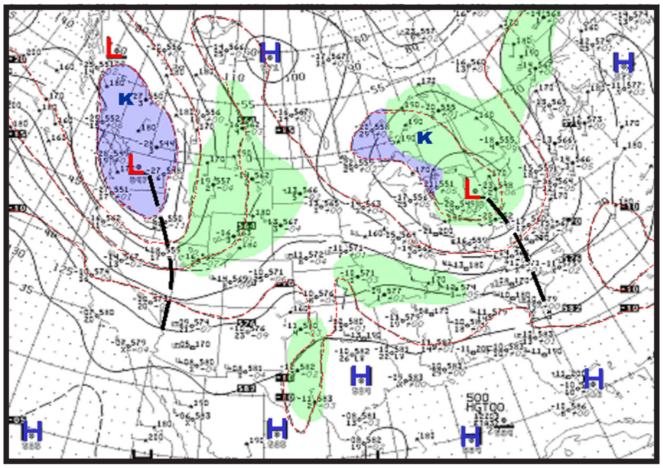

Figure 5-9. 500 mb 1200Z/3 June 2001. Subtropical ridging appears on the scene over the southern CONUS. As a result of this ridging, the sharpness of troughs over the southern CONUS weakens.

on the upper air charts for a week or more. Cutoff lows sometimes appear as a result of blocking patterns and may remain nearly stationary for days, until the block has broken down (see Figures 5-10 and 5-13). The frequency of occurrence for the cutoff low regime peaks in May.

Don't become confused between a closed low and a cutoff low. Cutoff lows are not associated with the primary westerly (and polar jet) flow as closed lows are. Cutoff lows, as an entity, have weak jet streams associated with them. Locations affected by these stagnant systems may experience the same weather conditions for several days in a row. Attempting to forecast the overall movement of a cutoff low is a challenge.

Two events will now be shown. Figures 5-10 through 5-18 depict two similar cutoff low systems that appeared over the eastern CONUS. In Figure 5-10, two cutoff lows are noted over the eastern and western CONUS. An east-to-west ridge is located over southern Canada. The polar jet lies mostly north of the ridge.

Another springtime cutoff low event that had occurred recently over the central and eastern CONUS is shown in Figures 5-11 through 5-18. Figure 5-11 depicts the

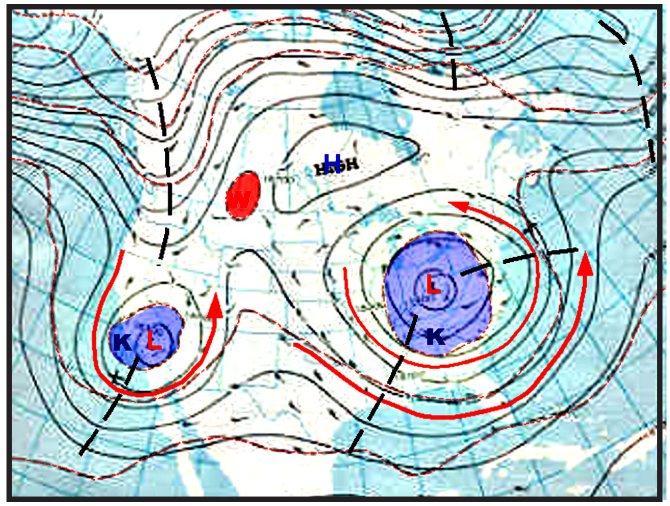

Figure 5-10. 500 mb 1200Z/29 April 1980. Two cutoff lows are shown over the CONUS with a closed high over southern Canada. The cutoff low shown over the eastern CONUS remained stationary for several days. NOTE: Another cutoff low is shown in Figure 5-13 over the central and eastern CONUS twenty-one years later.

upper level conditions prior to a cutoff low event. In Figure 5-11, a feature that may warn forecasters that a low may cut off is a narrowing of a trough such as shown

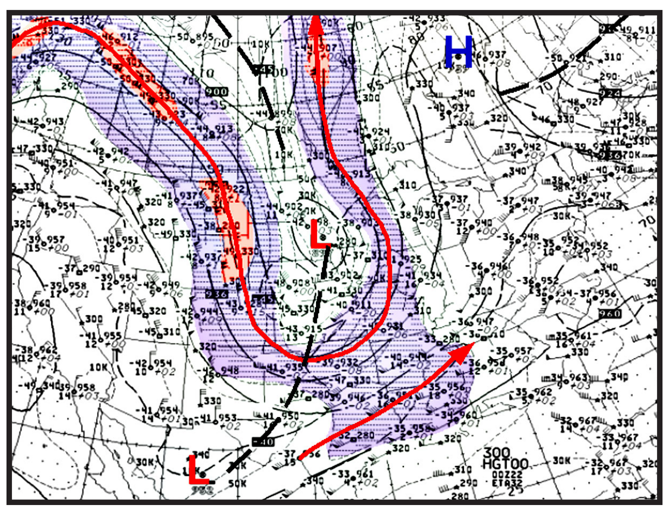

Figure 5-11. 300 mb, 0000Z/22 May 2001. The narrowing of the trough over the upper Great Plains suggests a possible cutoff low will develop.

over North Dakota and Minnesota. In this example, the low became a cutoff system within 48 hours (Figure 5-12). Another feature for possible development of a cutoff low is the elongated ridge shown in Figure 5-11 over eastern Canada and the eastern CONUS region.

Forty-eight hours later, a cutoff low and blocking high regime is evident over the eastern Canada/CONUS region (Figure 5-12). As can be seen in Figure 5-12, a wraparound jet is associated with the low. The main polar jet appears over northern Canada as noted by the arrows. The 500-mb chart is shown in Figure 5-13. A cutoff low and blocking regime is noted. The surface analysis, Figure 5-14, shows several fronts and troughs associated with this nearly stationary system.

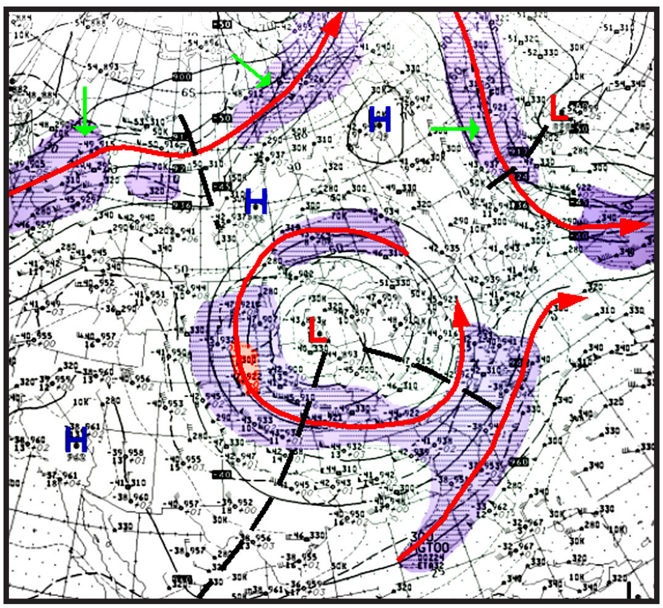

Figure 5-12. 300 mb, 0000Z/24 May 2001. The primary polar jet extends across northern Canada. A 70- to 100-knot jet surrounds the cutoff low.

As mentioned earlier, a cutoff low's movement is generally slow due to the absence of strong mid- and upper- level winds to move it along. In this example, the cutoff low persisted for a week over the northeastern CONUS as shown in Figures 5-15 and 5-16. In Figure 5-15, the circulation and associated jet stream have weakened considerably when compared to the system four days earlier (Figure 5-12).

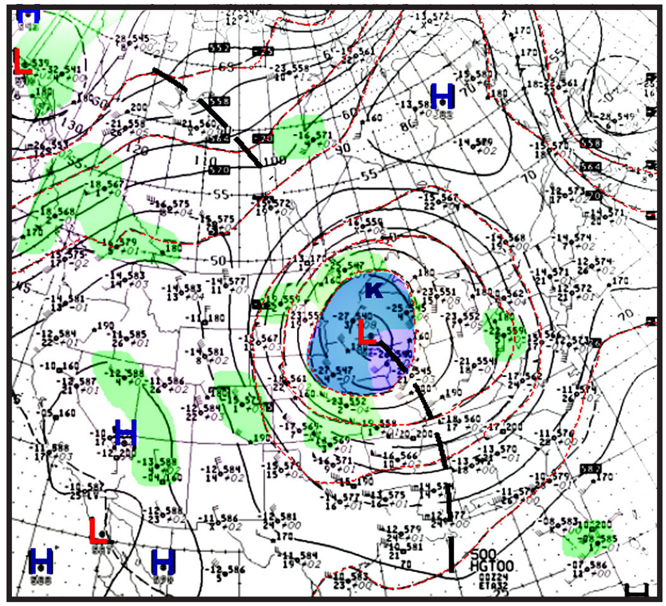

Figure 5-13. 500 mb 0000Z/24 May 2001.

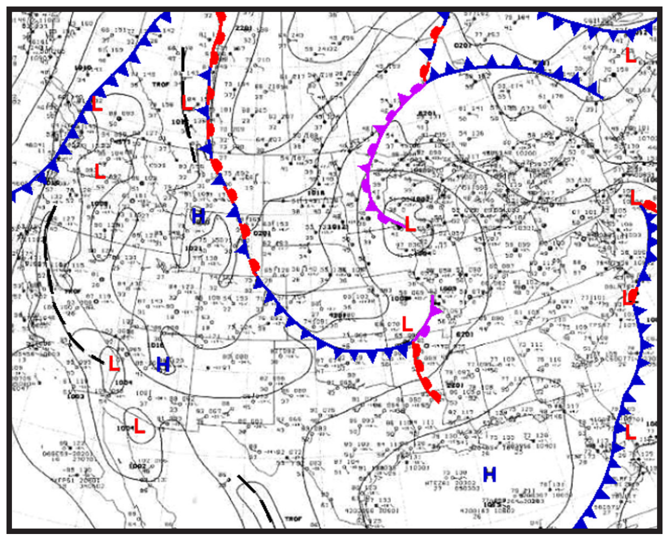

Figure 5-14. Surface, 0000Z/24 May 2001.

Figures 5-17 and 5-18 illustrate two GOES visible photos two days apart. In Figure 5-17, the cutoff low's baroclinic cloud systems are still intact (the system became a cutoff low 12 hours earlier).

In Figure 5-18, two days later, the center of circulation has shifted eastward into the Great Lakes region. The cloud systems appear to have thinned and become fragmented, as the low becomes barotropic (lessening directional wind shear and inphase height contours and isotherms).

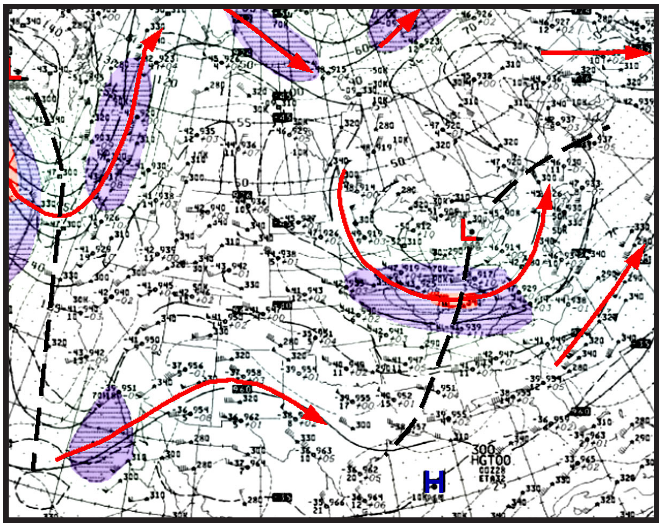

Figure 5-15. 300 mb, 0000Z/28 May 2001.

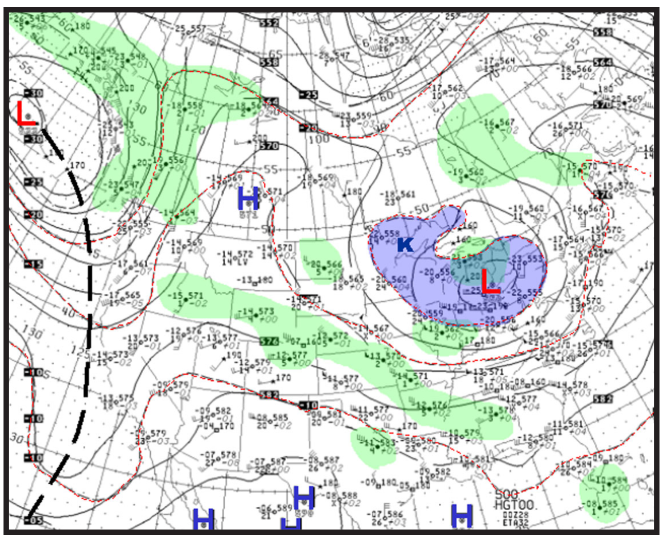

Figure 5-16. 500 mb, 0000Z/28 May 2001.

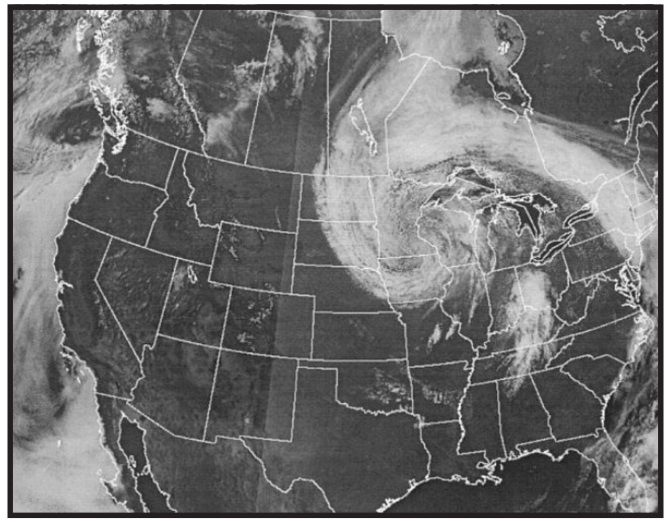

Figure 5-17. GOES E VIS, 1532/23 May 2001.

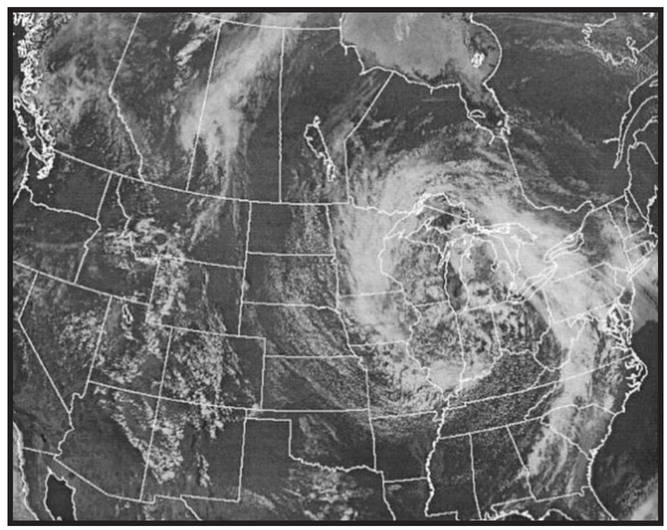

Figure 5-18. GOES E VIS Composite, 1940Z/25 May 2001.

Storm Tracks

At the onset of spring in mid-March and continuing into mid-April, winter-like storm systems, such as Alberta lows, Gulf of Mexico Lows and East Coast Lows, may affect the eastern CONUS. The most frequent cyclogenesis areas that affect the East Coast during spring are Colorado Lows and lows that develop along stationary fronts over the Great Plains.

Alberta Lows

The winter regime of rapidly-moving Alberta lows that produce significant snowfall over the Great Lakes and northeastern CONUS generally ends by late April. However, surface lows, associated with Pacific short waves that affect the Great Lakes and northeastern CONUS, continue to develop along the Alberta Rockies throughout spring and into summer. Figures 5-19 through 5-24 depict three examples.

The stationary front that lies along the Alberta and Montana Rocky Mountains in Figure 5-19 typifies the setup for Alberta Low development in association with an approaching Pacific short wave. During early spring, these systems may produce significant snowfall from the Dakotas eastward across Minnesota and Wisconsin to the northern Great Lakes (Figure 5-20)

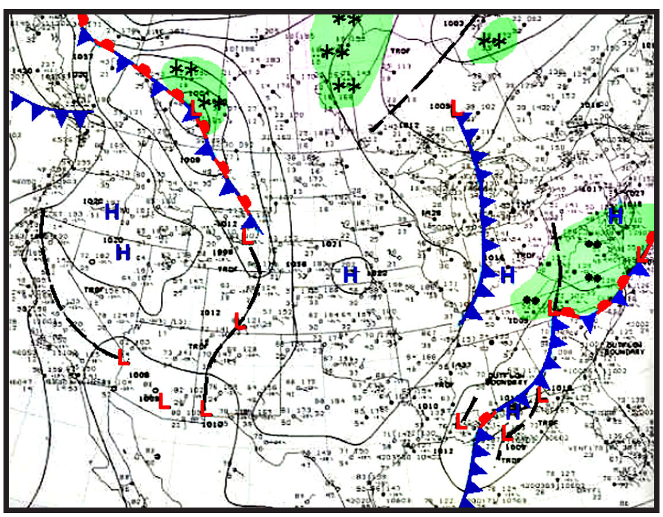

Figure 5-19. Surface, 2100Z/31 March 2002.

Another example is shown in Figures 5-21 through 5-23.

By the onset of summer, Alberta Low tracks are further to the north when the polar jet shifts northward as shown in Figures 5-24 through 5-26.

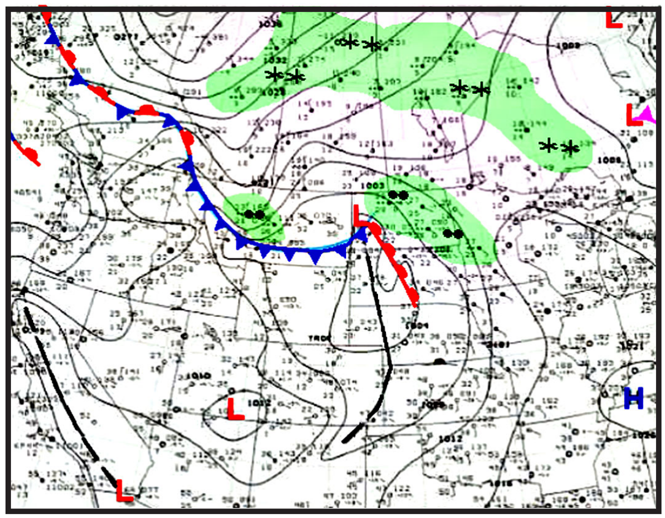

Figure 5-20. Surface 1200Z/1 April 2002.

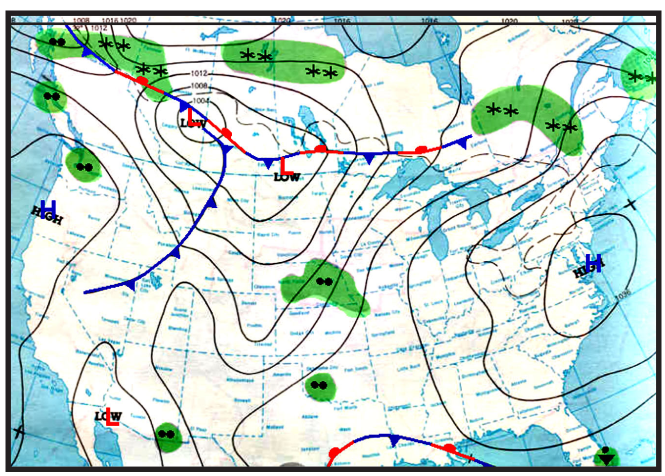

Figure 5-21. Surface, 1200Z/16 April 1981.

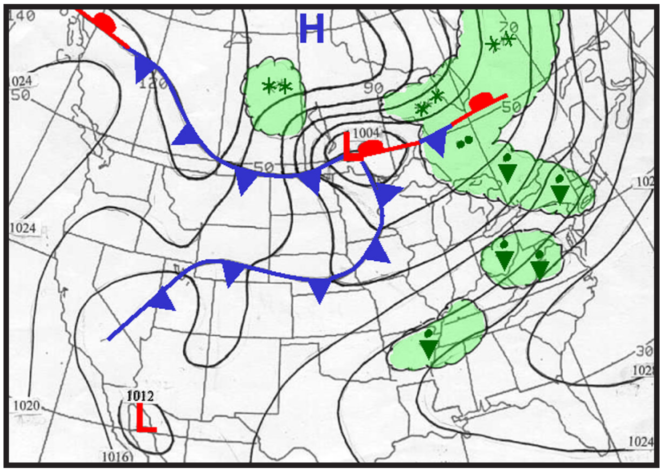

Figure 5-22. Surface, 1200Z/17 April 1981.

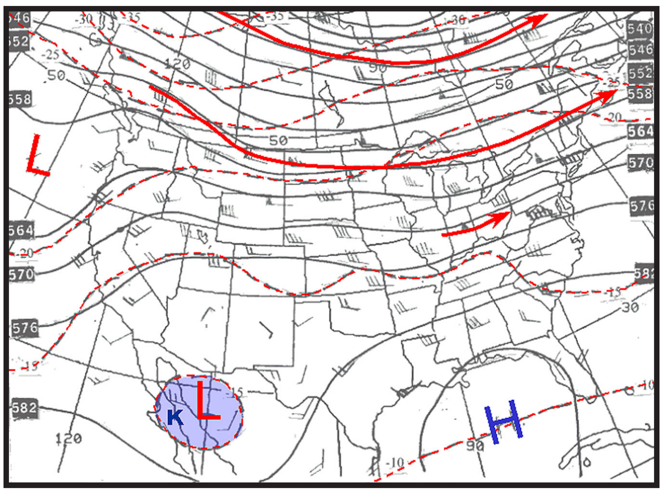

Figure 5-23. 500 mb, 1200Z/17 April 1981.

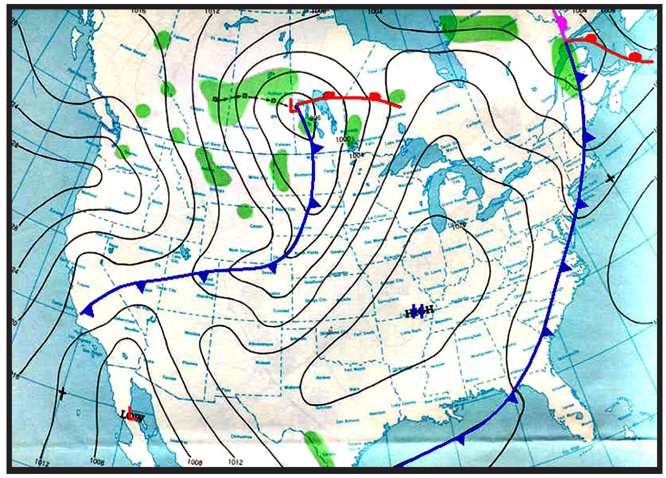

Figure 5-24. Surface, 1200Z/17 June 1981. Low formed along the Alberta Rockies as indicated by the continuity track shown in this figure.

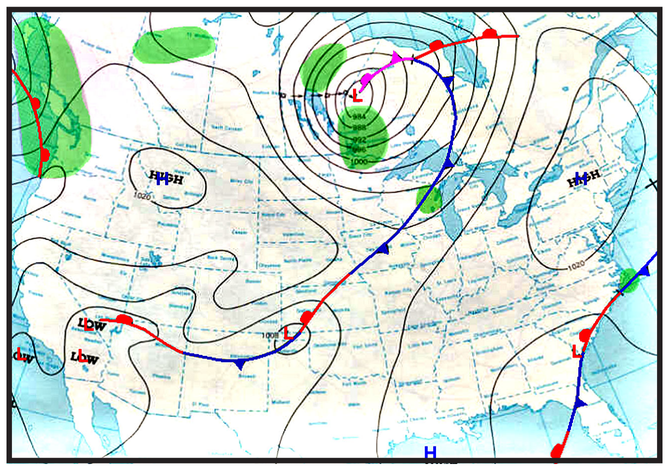

Figure 5-25. Surface, 1200Z/18 June 1981.

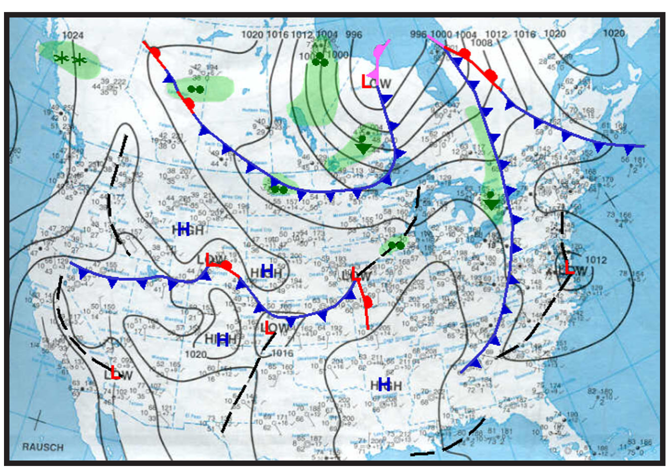

Figure 5-26. Surface, 1200Z/16 June 2001.

Gulf of Mexico Frontal Lows

Example 1 – 13-14 April 1980

Continuing from its winter regime, Gulf of Mexico frontal lows may occur through April and are generally associated with longwave troughs. These lows often track eastward along the Gulf Coast and they eventually lift northeastward across northern Florida and travel northward along the East Coast. In the example that follows (Figures 5-27 through 5-32), the Gulf Low lifted northeastward from Louisiana to the Great Lakes region rather than continuing eastward. In these events, the polar jet still lies across the southern CONUS. At the surface, cP air prevails across the central and northern CONUS. The mid-April storm system shown in Figures 5-27 through 5-32 produced an average of two to four inches of snowfall from northern Arkansas to the Great Lakes (Figure 5-31). The satellite picture, Figure 5-32, shows the extent of this storm system. Although Gulf of Mexico lows that move northward towards the Great Lakes do not occur that often in spring, especially to produce significant snowfall, this event is included so that forecasters are aware that the potential does exist.

In Figure 5-27, two split-flow short waves are shown within a longwave trough. The southern short wave over Texas is lagging behind and is undergoing further deepening while the northern short wave pulls away. The thermal pattern shows strong cold air within the southern short wave.

The related surface conditions are depicted in Figure 5-28. Continental polar air prevails over the northern and central regions of the CONUS. A typical overrunning precipitation regime is associated with the Gulf of Mexico low.

In Figure 5-29, the upper low has lifted northeastward into the mid-Mississippi Valley area. A cold pocket is noted over the southern Great Plains. This pocket moved northeastward and interacted with the developing comma cloud to produce a swath of 2-4 inches of snow (Figure 5-31).

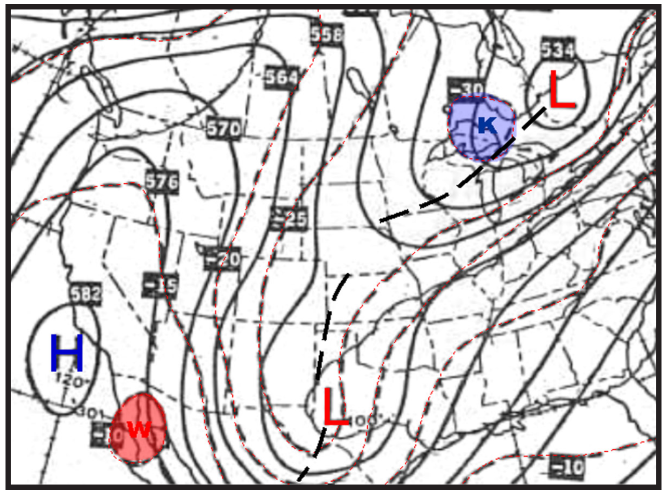

Figure 5-27. 500 mb, 1200Z/13 April 1980.

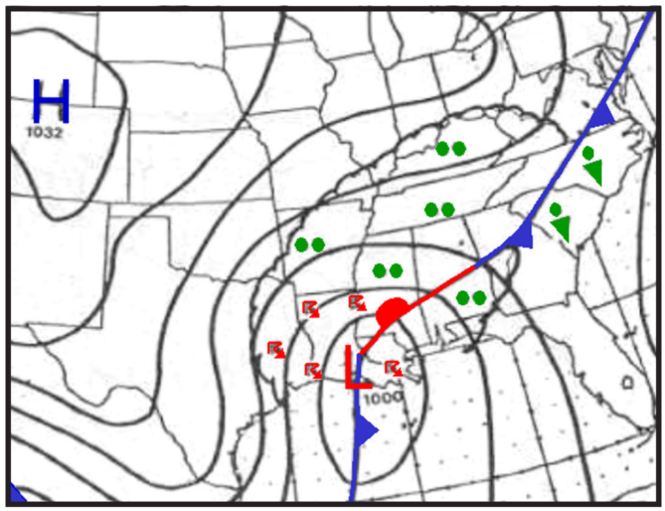

Figure 5-28. Surface, 1200Z/13 April 1980.

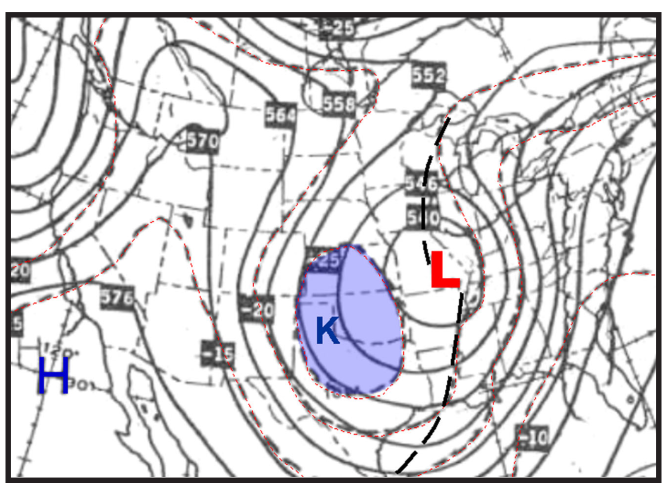

Figure 5-29. 500 mb, 1200Z/14 April 1980.

At the surface, the Gulf low has lifted northeastward in response to the movement of the upper low (Figure 5-30). Continental polar air advected into the system over the Mississippi Valley area and resulted in snowfall north and northwest of the comma.

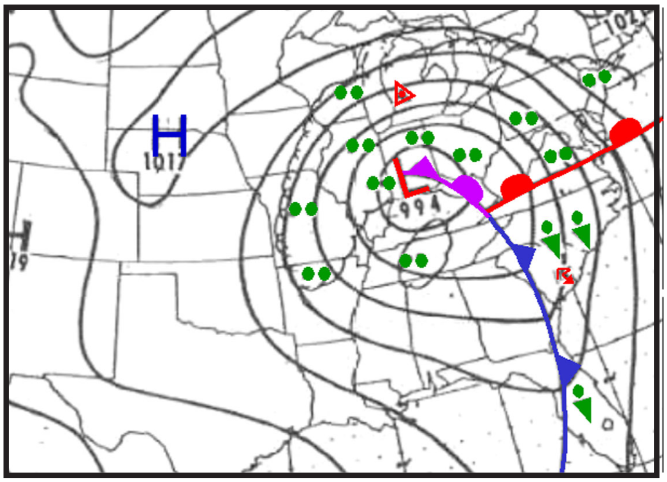

Figure 5-30. Surface, 1200Z/14 April 1980.

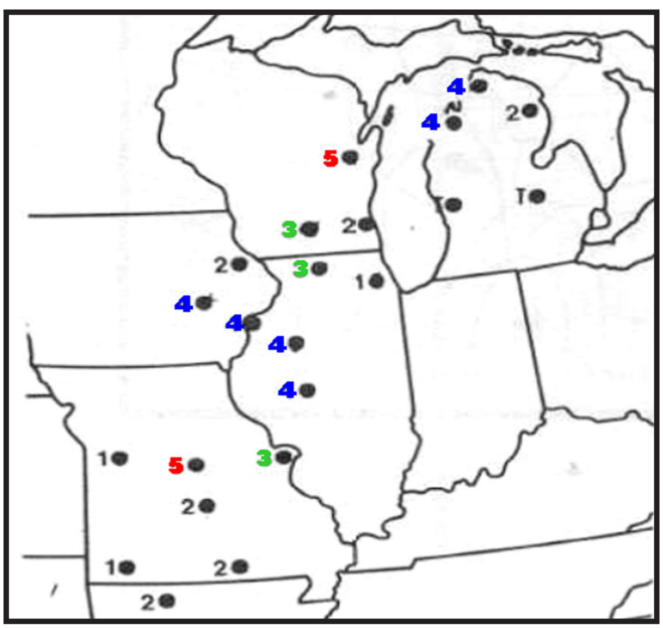

Figure 5-31. Snowfall 14-16 April 1980.

The snowfall amounts for a two-day period are shown in Figure 5-31. Figure 5-32 depicts the mature comma cloud system that extends from the central plains to the East Coast.

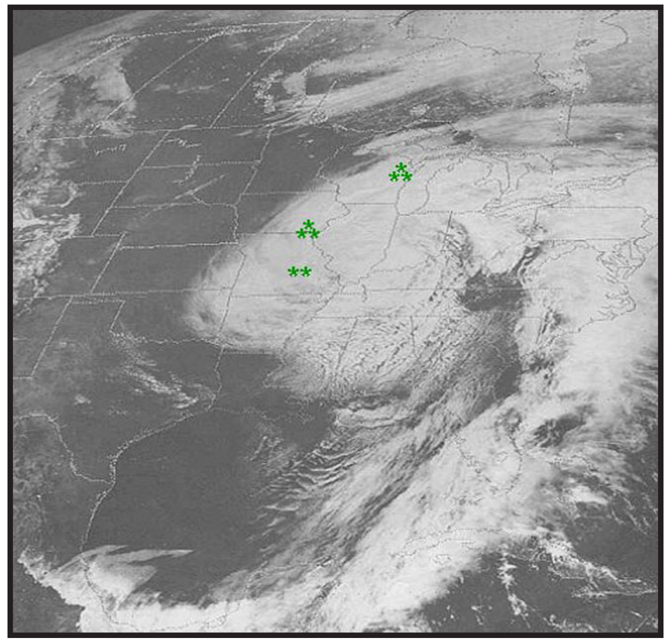

Figure 5-32. GOES E VIS, 1816Z/14 April 1980. A pronounced precipitation shield is shown from Michigan to Arkansas. Snow is noted within the cloud system.

Atlantic Coastal Lows

Example 1, 23 March 2001

The winter regime of Atlantic coastal lows over the northeastern CONUS that produce significant precipitation and strong surface winds is likely through April and occasionally may appear in May. A late March event is shown in Figure 5-33. During early spring the potential for significant snowfall over the inland areas should always be considered as these lows track northward along the coast.

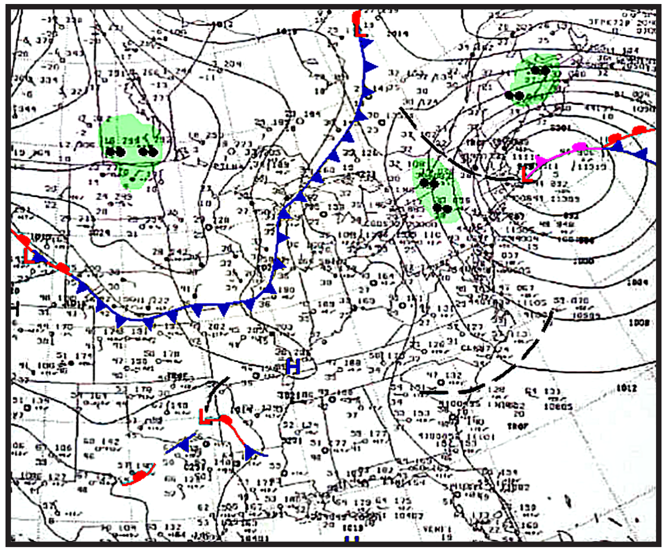

Figure 5-33. Surface, 0300Z/23 March 2001.

Example 2, 16-17 April 2001

Another early spring example where an approaching short wave deepened within a long wave trough over the eastern CONUS is shown in Figures 5-34 through 5-36.

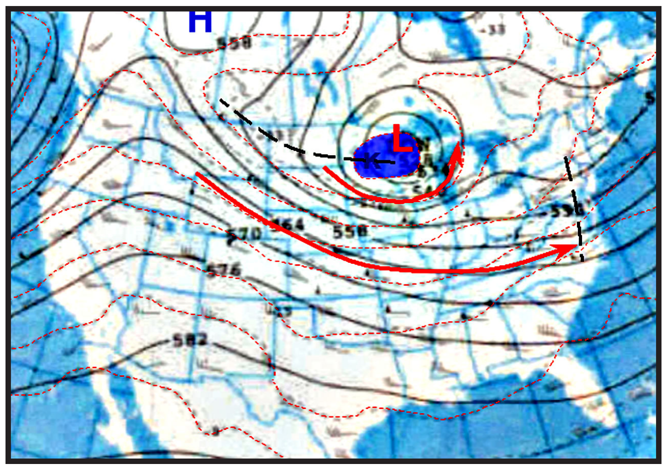

Figure 5-34. 500 mb, 1200Z/16 April 2001.

At the 500-mb level, Figure 5-34, a closed low is shown over the Great Lakes. A strong ridge lies over the western Canada/CONUS region. The associated surface low shown in the Lake Superior region (Figure 5-35) stacks with the upper low. Another player in this event is the low located off the eastern seaboard as shown in Figure 5-35. Several winter case studies have been documented where stationary offshore lows deepen rapidly when inland short waves approach. The surface system, associated with the inland short wave, will fill while the offshore low deepens. In *Winter Regimes*, an excellent example was presented in Chapter Six.

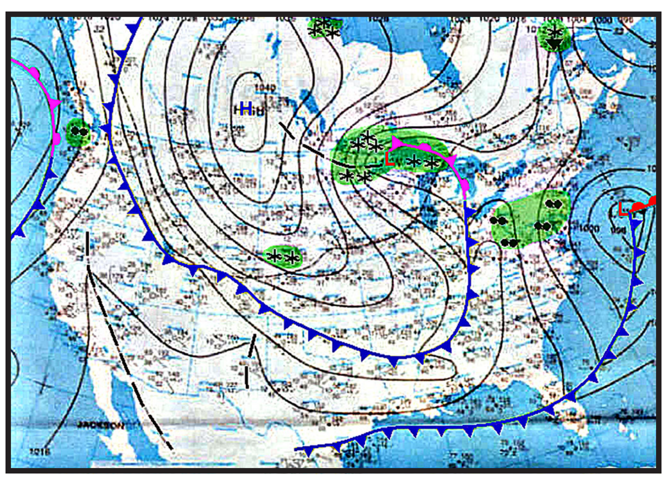

Figure 5-35. Surface, 1200Z/16 April 2001.

The next 24-hour set is depicted in Figures 5-36 and 5-37. In Figure 5-36, the 500-mb low has dropped southward into Ohio as the shortwave trough continues to deepen within the long wave. Meanwhile the western North America ridge continues to build. The Great Lakes surface low shown in Figure 5-35 has continued to fill and is represented as an east-west trough in Figure 5-37. Also in Figure 5-37, the offshore low shown in Figure 5-35 has moved northwestward and lies off the New Jersey coast. The low's northwestward movement is in response to the approaching upper low.

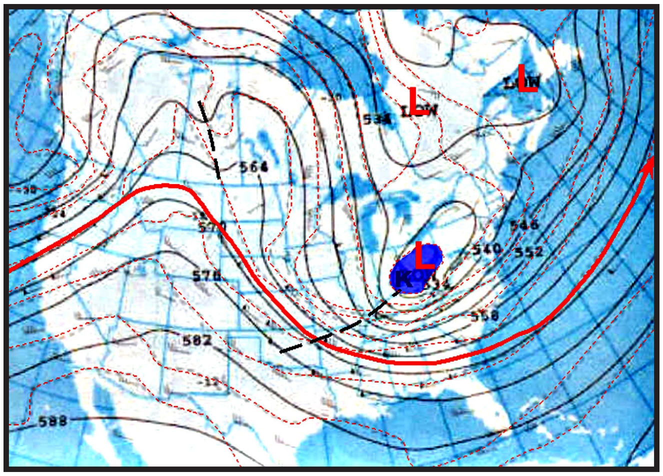

Figure 5-36. 500 MB, 1200Z/17 April 2001.

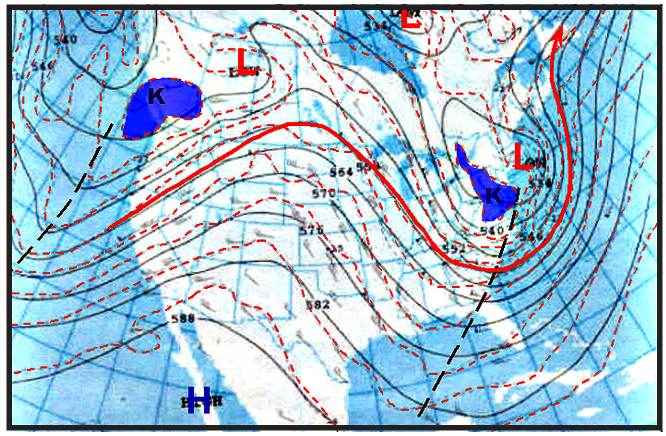

Figure 5-38. 500mb, 1200Z/18 April 2001.

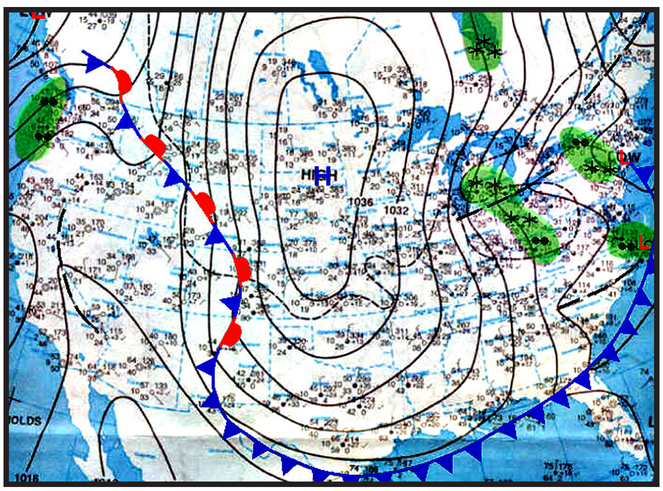

Figure 5-37. Surface, 1200Z/17 April 2001.

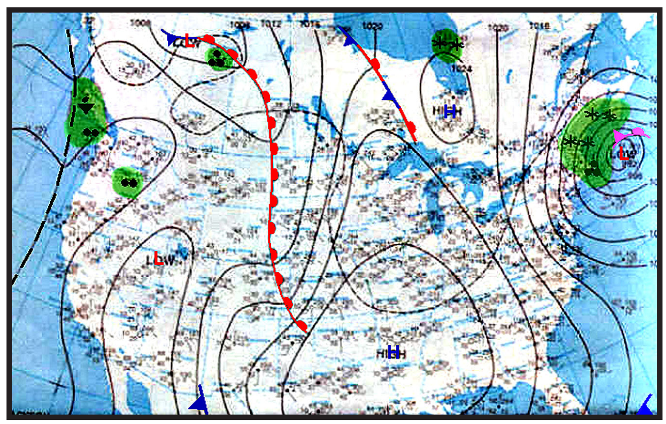

Figure 5-39. Surface, 1200Z/18 April 2001.

The final two figures are shown in Figures 5-38 and 5-39. In Figure 5-38, the 500-mb low that was located over Ohio 24 hours ago has bottomed out, moved northeastward and appeared along the New Jersey coast. The surface low shown along the New Jersey coast 24 hours earlier (Figure 5-37), has deepened as it lifts northward along the New England coast (Figure 5-39).

Colorado or Great Plains Lows

As previously shown in the short wave examples, Pacific short waves continue to track across the nation. Continuing from winter, many storm systems that affect the eastern CONUS are born or deepen either along the lee slopes of the Rocky Mountains or along fronts over the central and northern Great Plains. Several examples will be shown.

Colorado Lows

A frequent cyclogenesis region for Great Plains and eventually East Coast storm systems during spring is the area along and east of the Front Range of Colorado. A typical Colorado Low and its subsequent track across the Great Plains and East Coast are shown in selected examples in Figures 5-40 through 5-49. This is the most frequent and familiar cyclogenesis regime that occurs within the CONUS throughout the year.

Figure 5-40 illustrates the extensive cloud cover in place approximately 24 hours prior to Colorado Low formation. An east-to-west warm front lies across central Texas and the Gulf coastal states, and has resulted in extensive overrunning north of the warm front.

Figures 5-41 and 5-42 respectively depict the 500-mb and surface analyses approximately 24 hours later from Figure 5-40. In Figure 5-41, a shortwave trough has moved over the Rocky Mountains. The surface response to the approaching short wave is the low that appears over eastern Colorado in Figure 5-42. The extent of the precipitation with this storm is shown in Figure 5-43 (two hours later from Figure 5-42).

Figure 5-44 shows the 500-mb analysis 24 hours later from Figure 5-41. The shortwave trough has moved into the eastern CONUS.

How did the ETA model forecast this system? The 24-hour heights/vorticity forecast is shown in Figure 5-45 (based on the 1200Z/27 April input). The short wave's forecast location was right on target when comparing Figure 5-44 to Figure 5-45.

The surface analysis and 24-hour ETA surface forecast are respectively shown in Figures 5-46 and 5-47. Again, the 24-hour ETA surface forecast shown in Figure 5-47 compares favorably with actual analysis depicted in Figure 5-46.

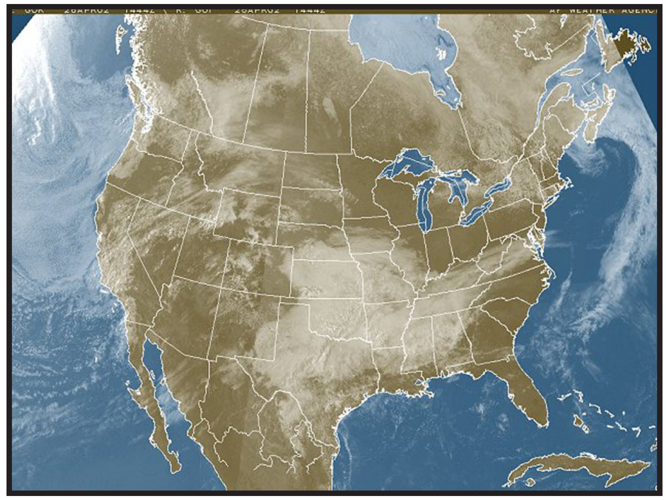

Figure 5-40. GOES E and W VIS, 1444Z/26 April 2002. Overrunning of moist air lifting over the warm front located across central Texas and Louisiana (Figure 5-42), and upper level moisture associated with the short wave has produced a large area of cloudiness.

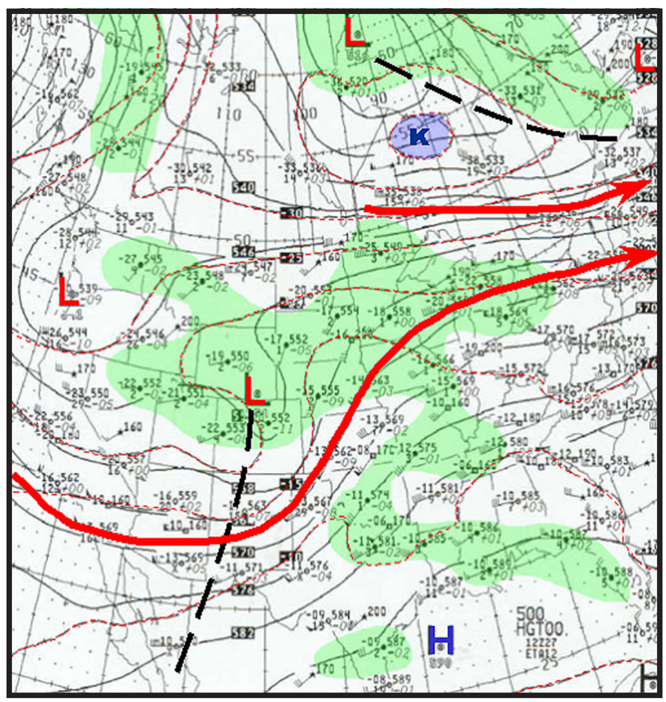

Figure 5-41. 500mb, 1200Z/27 April 2002.

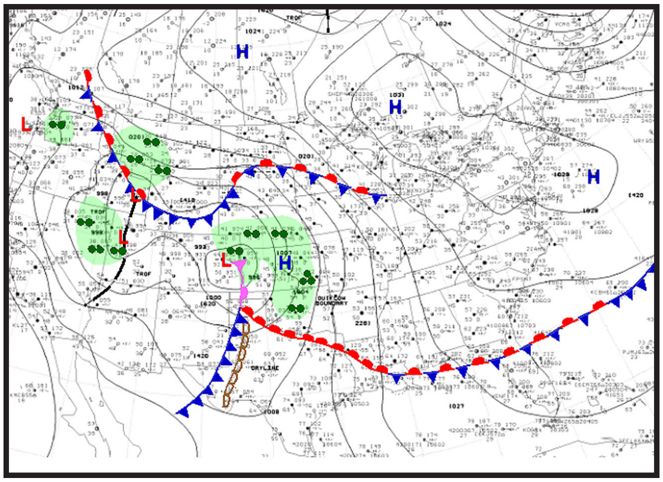

Figure 5-42. Surface, 1200Z/27 April 2002.

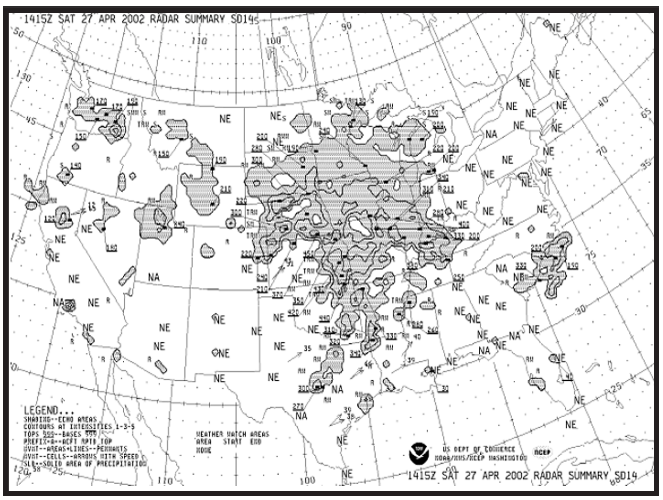

Figure 5-43. Radar Summary, 1415Z/27 April 2002.

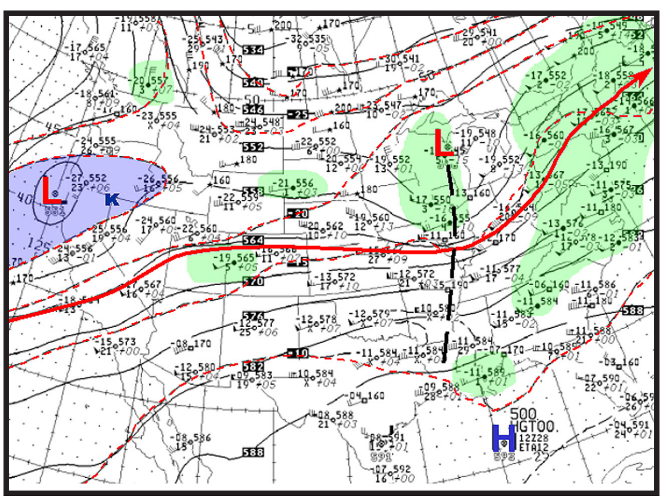

Figure 5-44. 500mb, 1200Z/28 April 2002.

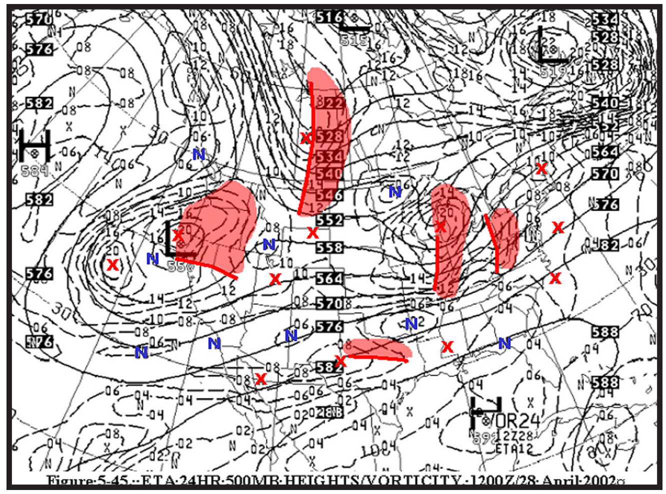

Figure 5-45. ETA 24HR 500MB HEIGHTS/VORTICITY, 1200Z/28 April 2002.

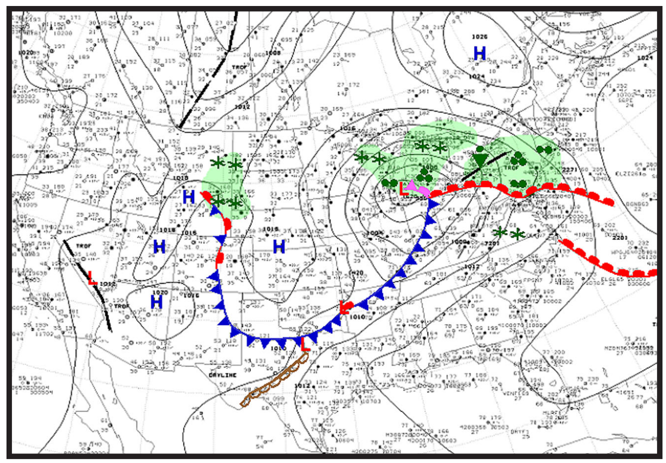

Figure 5-46. Surface, 1200Z/28 April 2002.

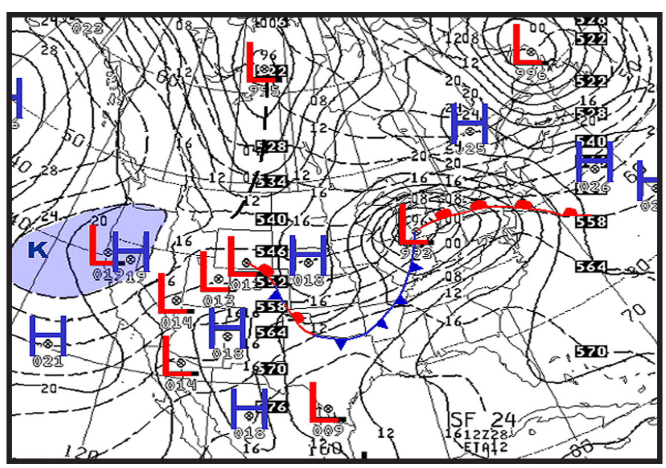

Figure 5-47. ETA 24HR MSL PRES/1000-500 THCKNS, 1200Z/28 April 2002.

Radar coverage over the eastern CONUS is shown in Figure 5-48. Finally, in Figure 5-49, the water vapor image reveals the three primary cloud subsystems that composed a comma cloud as seen in satellite photos.

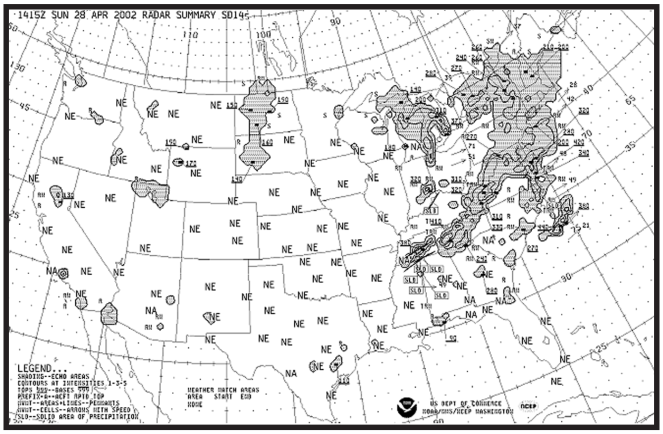

Figure 5-48. Radar Summary, 1415Z/28 April 2002.

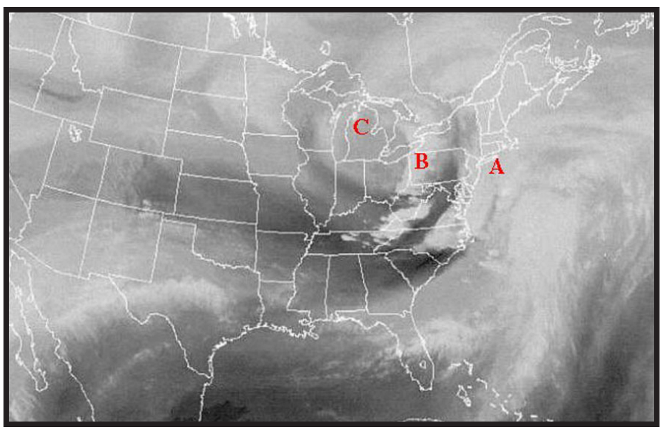

Figure 5-49. GOES E WV, 1845Z 28 April 2002. The three primary clouds system of a large comma stand out in this water vapor image. The baroclinic cloud system appears along the East Coast (A). The vorticity comma lies further to the west over western New York to West Virginia (B). Moisture associated with the comma head is shown over the Great Lakes (C).

Great Plains Lows

Another favorite region for cyclogenesis is along frontal systems that have become stationary over the Great Plains as a result of a northward shift of the polar jet and accompanying short wave systems. However, short waves that do drop southward into the central Great Plains and approach these fronts often initiate cyclogenesis. These storm systems often affect the eastern CONUS with increased precipitation and cold frontal severe thunderstorms. An example is now shown in Figures 5-50 through 5-56.

Figure 5-50 shows the 500-mb pattern at the start of frontal cyclogenesis over the upper Great Plains. A typical short wave with a developing upper low over Montana is shown over the western CONUS. The morning visible image is shown in Figure 5-51.

In Figure 5-52, a frontal wave has formed along the front in northern Iowa (illustration is nine hours later from Figure 5-50). Warm frontal rains are occurring over the Great Lakes.

In Figure 5-53a, the radar summary represents the precipitation areas related to Figure 5-52. Severe thunderstorm watch boxes are forecast, ahead of the strengthening cold front and dry line, as these two systems move into a moist and unstable air mass.

Figure 5-53b shows the severe thunderstorm reports beginning approximately two hours later from Figure 5-53.

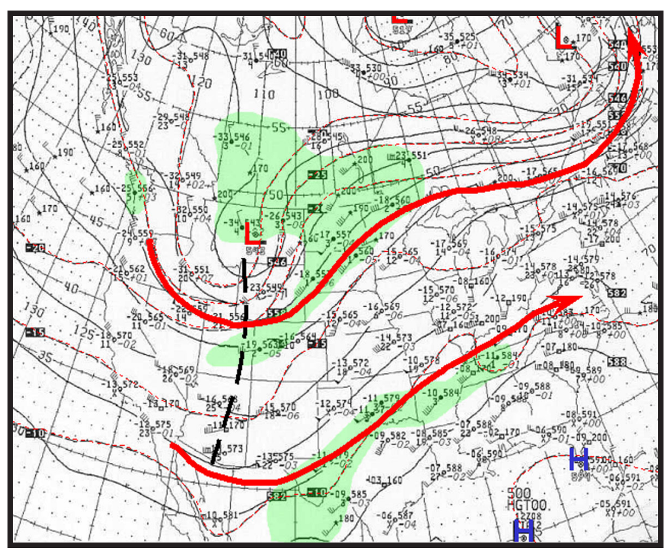

Figure 5-50. 500 mb, 1200Z/8 May 2002. Strong cold air advection behind the trough over Idaho and Montana should continue to deepen the trough.

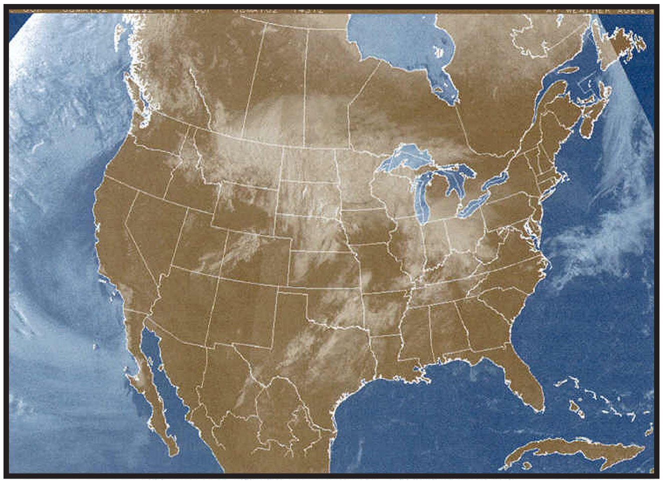

Figure 5-51. GOES E and W VIS, 1430Z/8 May 2002.

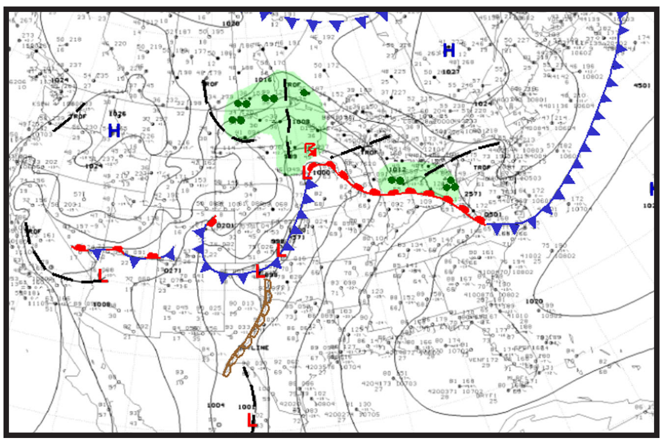

Figure 5-52. Surface, 2100Z/8 May 2002.

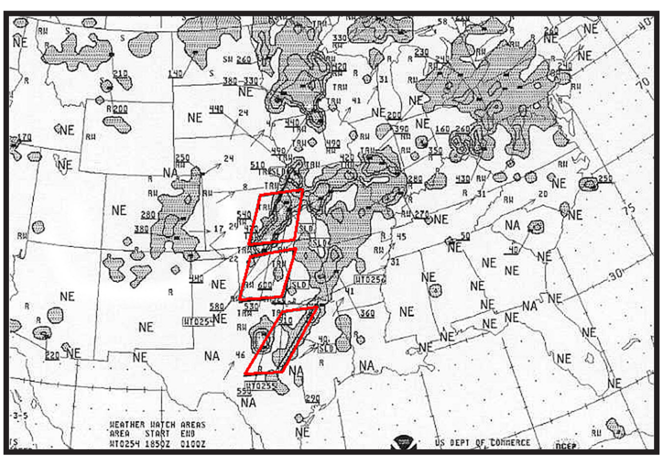

Figure 5-53a. Radar Summary, 2215Z/8 May 2002. Tornado watch boxes have been issued along the dry line from Texas to Kansas.

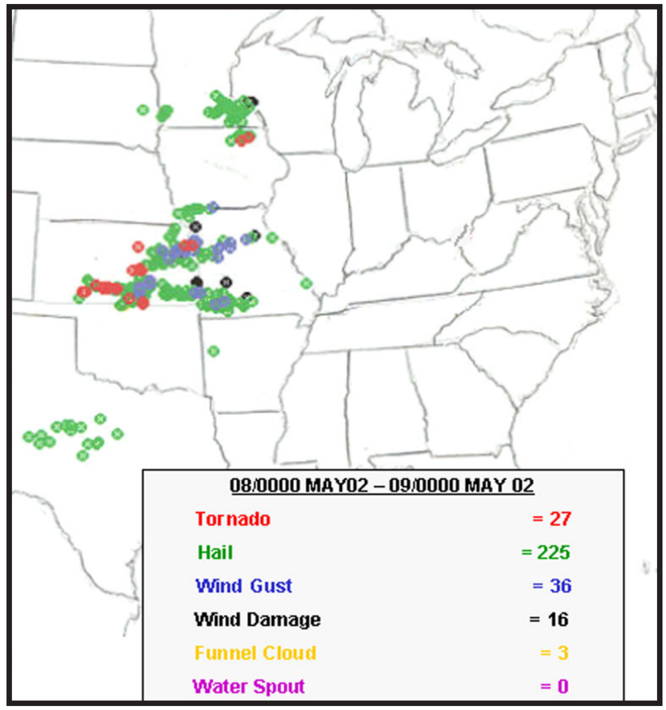

Figure 5-53b. Severe Thunderstorm Reports, 0000Z/8 May 2002 to 0000Z/9 May 2002. Courtesy Air Force Weather Agency's Severe Weather Unit.

The short wave's cloud structure over the Great Plains is revealed in the water vapor image shown in Figure 5-54.

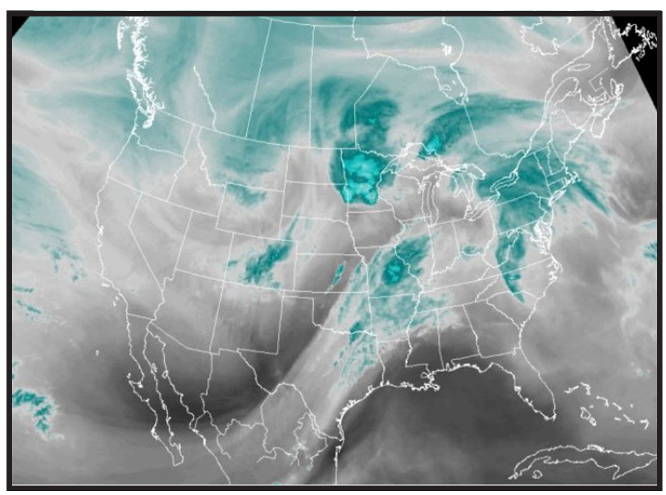

Figure 5-54. GOES W and E Composite, 1959-2009Z/8 May 2002. Photo courtesy of JAAWIN.

Twenty-four hours later, the short wave has moved into the Great Plains. A closed low appears within the trough over North Dakota as depicted in Figure 5-55.

In Figure 5-56, the surface low previously shown over Iowa in Figure 5-52 has intensified over the Great Lakes during the past 24 hours. Several squall lines have developed ahead of the cold front over the Appalachian Mountains, as depicted in the radar summary chart in Figure 5-57a.

Figure 5-57b depicts severe thunderstorms associated with cold front as it moves eastward to the East Coast by the end of period.

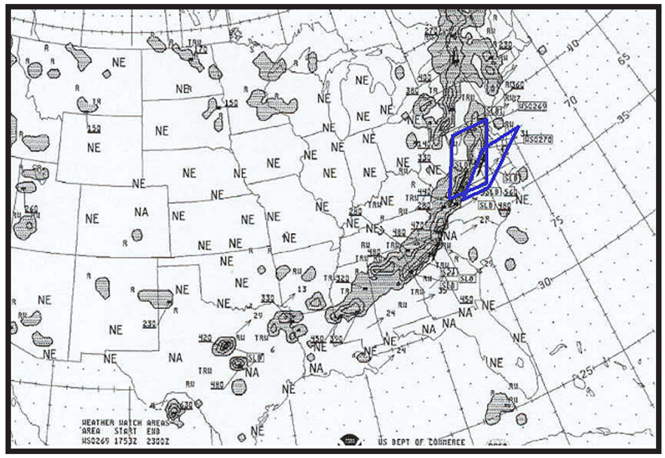

Figure 5-57a. Radar Summary, 2215Z/9 May 2002.

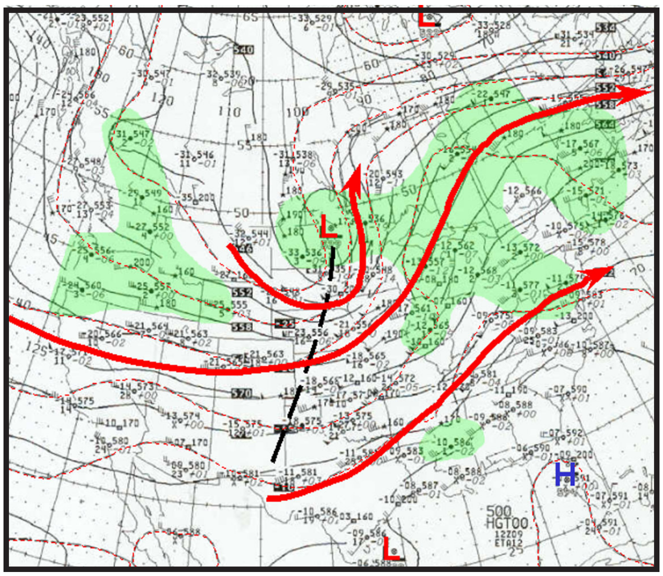

Figure 5-55. 500 mb, 1200Z/9 May 2002.

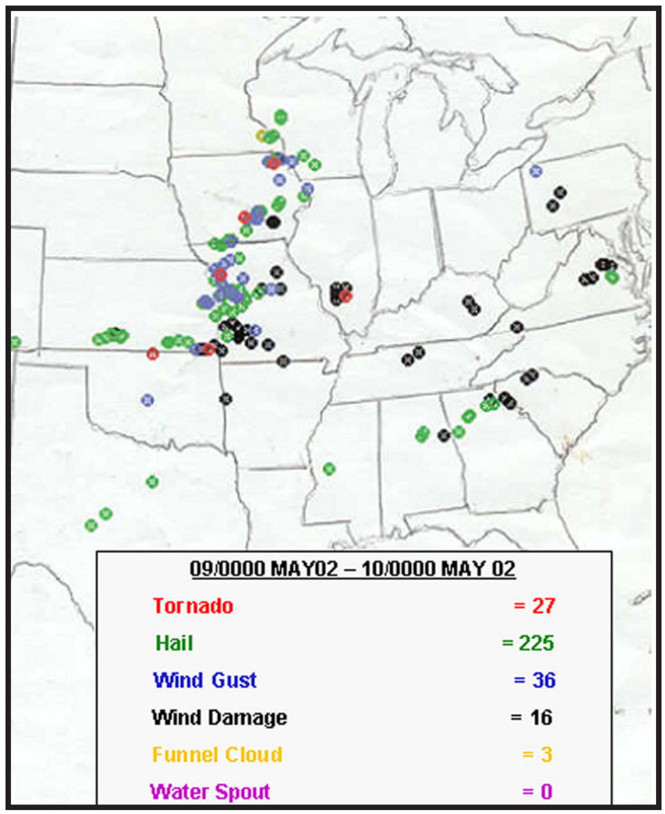

Figure 5-57b. Severe Thunderstorm Reports, 0000Z/9 May 2002 to 0000Z/10 May 2002. Severe reports shown from Wisconsin to Texas occurred early in the period. Courtesy Air Force Weather Agency's Severe Weather Unit.

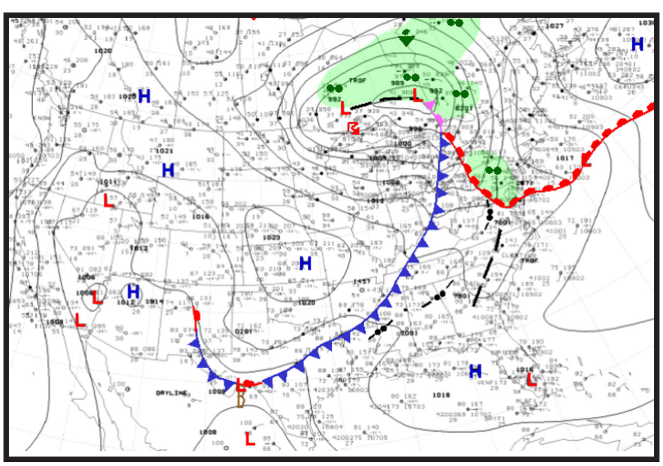

Figure 5-56. Surface, 2100Z/9 May 2002.

The late afternoon water vapor image, Figure 5-58, reveals thunderstorm lines associated with the cold front. Severe thunderstorm outbreaks that occurred over the Great Plains several days earlier continued through the period as the cold front moved into the eastern CONUS.

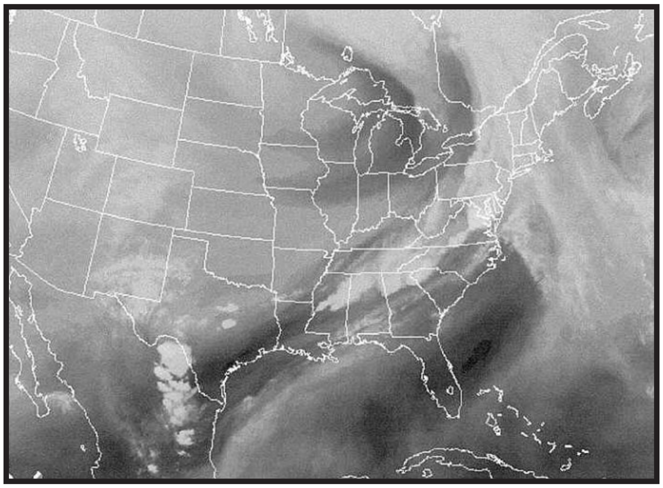

Figure 5-58. GOES E WV, 2245Z/9 May 2002.

Fronts and Air Masses

Continental Polar (cP) Fronts/Air Masses

Continental polar fronts and air masses continue to prevail over the eastern CONUS through May as shown in Figures 5-59 and 5-60. The Great Lakes region and the northeastern CONUS may experience snow events through April due the passage of Canadian air masses. By early June, strong cP air masses generally do not penetrate into the Deep South.

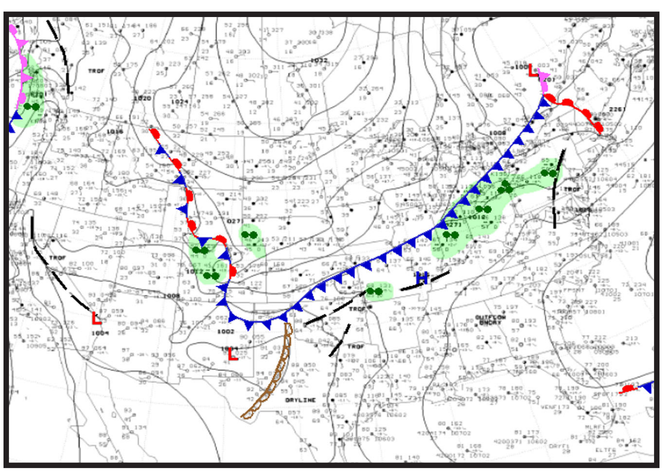

Figure 5-59. Surface, 0000Z/17 May 2002.

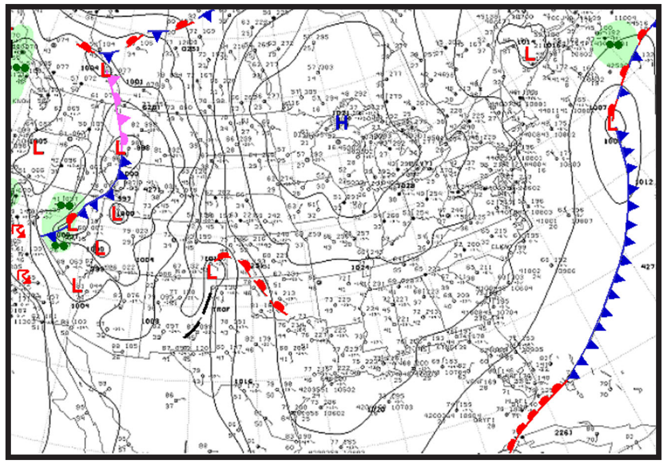

Figure 5-60. Surface, 2100Z/20 May 2002.

Maritime Polar (mP) Fronts/Air Masses

Pacific maritime polar fronts from the western CONUS become the dominant frontal regime in June. As has been shown earlier, mP cold fronts emerging from the Rocky Mountains are often the triggers for cyclogenesis and further intensification over the Great Plains and eastward. By late spring and continuing through summer, the cores of cP air masses generally are confined across Canada with frontal intrusions into the northern CONUS. Figure 5-61 and 5-62 illustrate two maritime polar events.

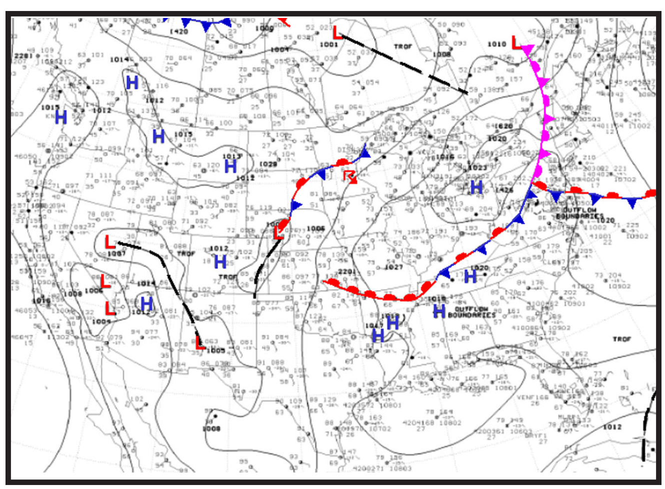

Figure 5-61. Surface, 2100Z/26 May 2002. Maritime polar fronts are shown across the nation.

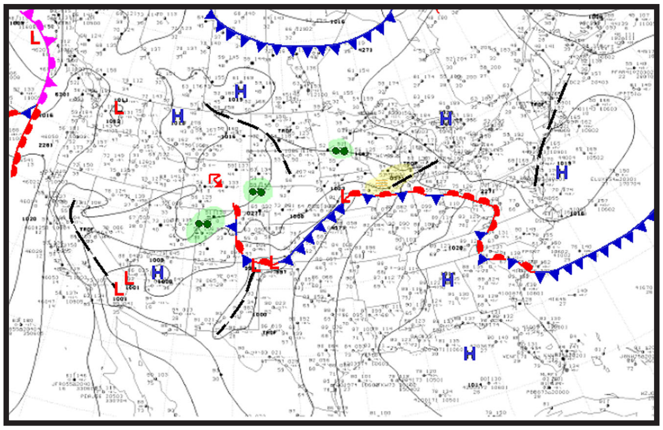

Figure 5-62. Surface, 0000Z/4 June 2002.

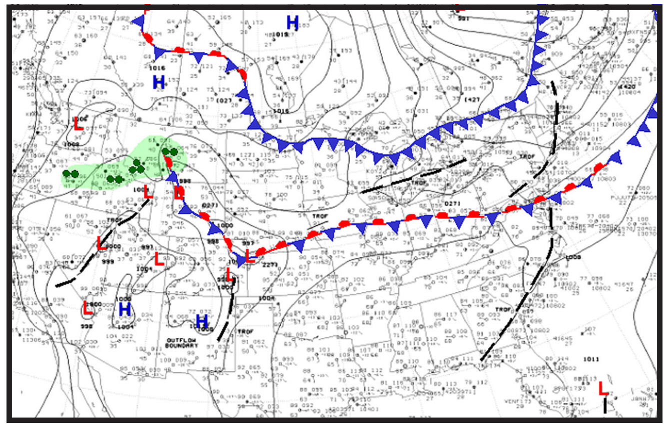

Figure 5-63. Surface, 0000Z/2 June 2002.

Stationary Fronts

Toward the end of spring and continuing through summer, fronts often become stationary as the mid-level steering wind speeds decrease due to increased ridging and a northward shift of the stronger westerlies. Figures 5-63 and 5-64 depict two events.

During late spring, stationary fronts weaken to the point that they are difficult to locate on the surface analyses and may be shown as surface troughs. These weakened fronts should not be ignored, especially when the air mass is highly unstable and moist. Convection will develop quickly as the earth warms. An example follows: In Figure 5-65, the CONUS is under a weak pressure gradient regime. Several surface troughs are noted, along with outflow boundaries left over from previous convection. These boundaries are important.

In Figure 5-66, approximately one hour later than Figure 5-65, considerable convection is noted across the CONUS. Several weather watches are also shown over the Great Plains. Considerable thunderstorm activity is shown over the eastern CONUS. As the reader can see, surface troughs, outflow boundaries and convergent zones within moist, unstable air masses will produce considerable convection.

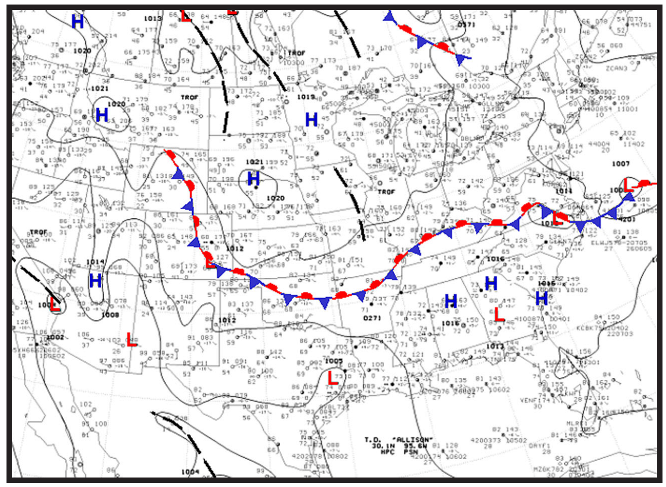

Figure 5-64. Surface, 0000Z/8 June 2001.

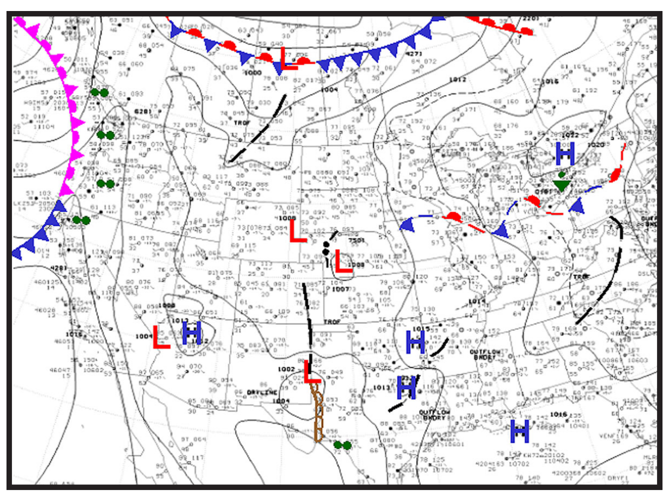

Figure 5-65. Surface, 0000Z/28 May 2002.

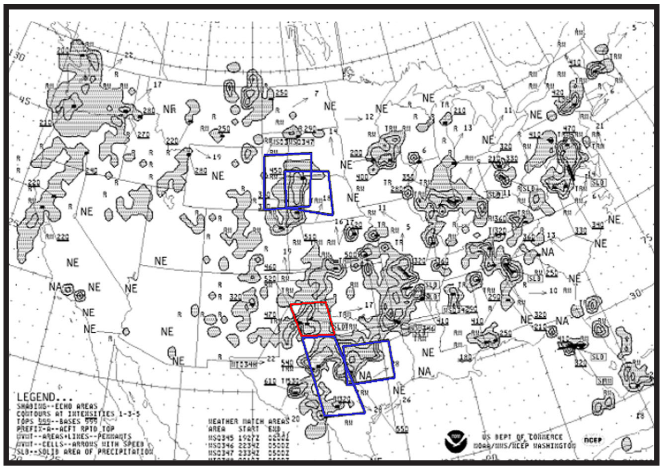

Figure 5-66. Radar Summary, 0115Z/28 May 2002.

Frontal Cyclogenesis

Frontal cyclogenesis over the eastern CONUS is likely through the period. During March and April, many storm systems are still associated with the polar jet. Toward the end of April and continuing through May, frontal cyclogenesis over the southeastern CONUS is associated with weaker upper air disturbances such as cutoff lows (Figures 5-67 and 5-68).

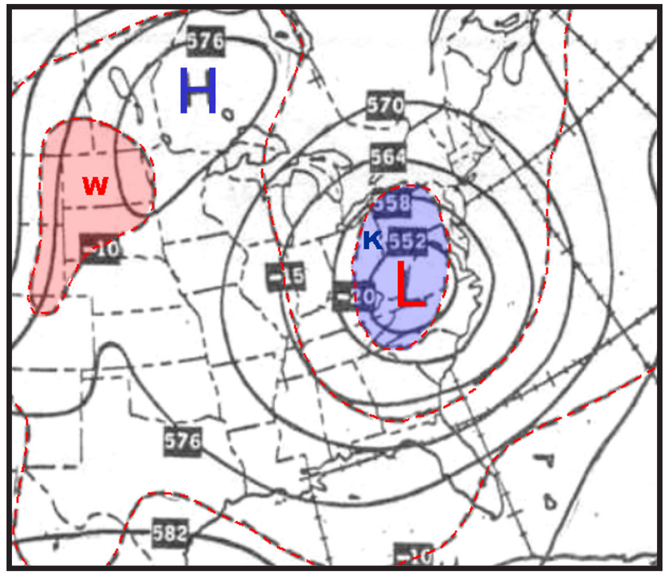

Figure 5-67. 500 mb, 1200Z/Mid May.

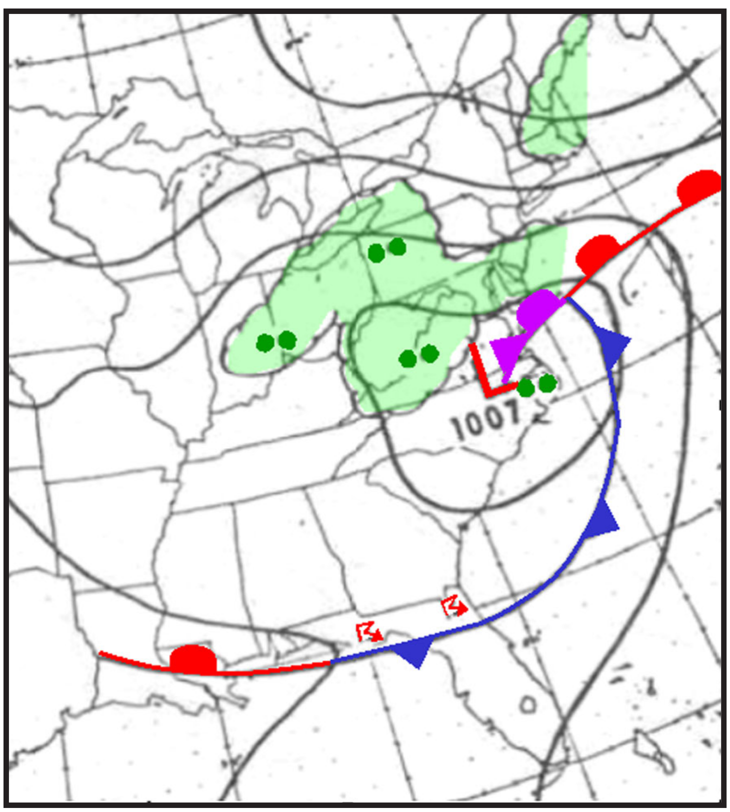

Figure 5-68. Surface, 1200Z/Mid May.

Thunderstorms

Cold Frontal Thunderstorms

By early spring, frontal thunderstorms (often severe) increase significantly over the eastern CONUS as depicted in Figures 5-69 through 5-74. Figures 5-69 and 5-70 illustrate cold frontal thunderstorms associated with mature low-pressure systems over the eastern CONUS.

Two more examples of cold frontal thunderstorms are shown in Figures 5-71 through 5-74. In these two events, thunderstorms developed along continental polar fronts that moved southward into moist and unstable air masses across the eastern CONUS (Figures 5-71 and 5-73). The associated radar summary charts are depicted in Figures 5-72 and 5-74. Severe thunderstorms occurred along these cold fronts as shown by the watch boxes issued by the Storm Prediction Center (SPC).

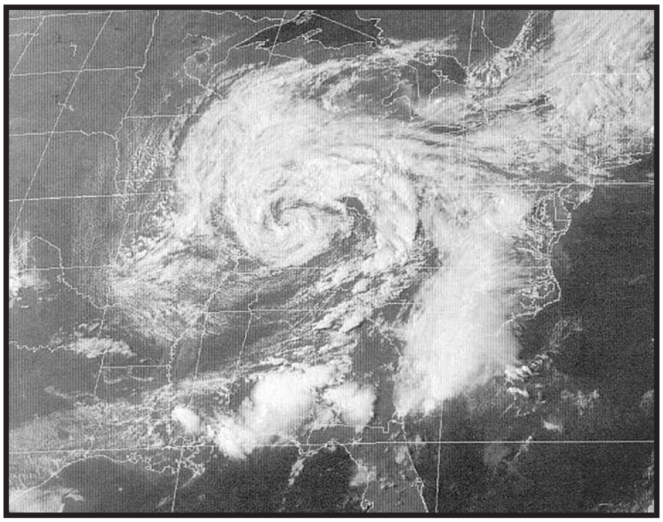

Figure 5-69. GOES E VIS, 2130Z/3 May 1998.

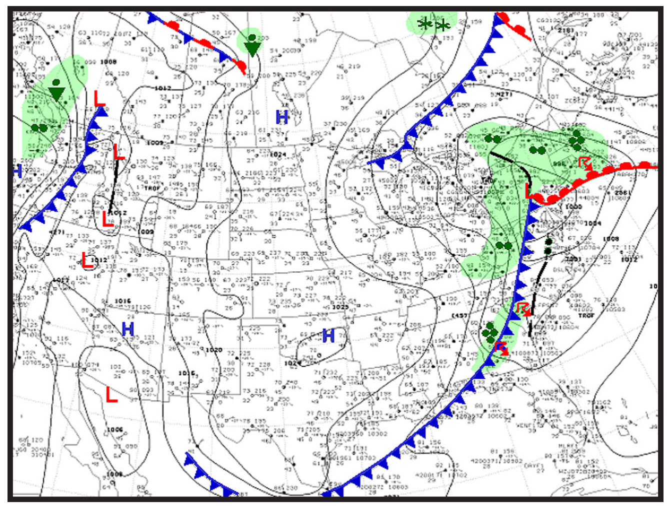

Figure 5-71. Surface, 0000Z/14 May 2002.

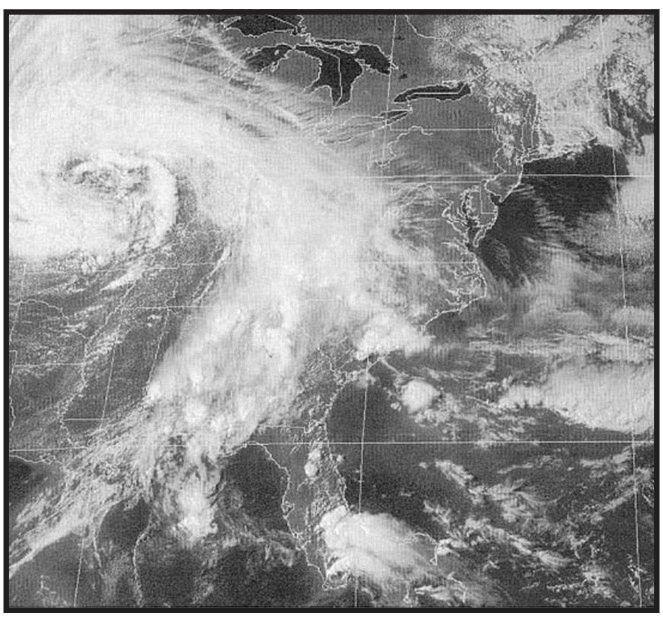

Figure 5-70. GOES E VIS, 2115Z/27 April 1999.

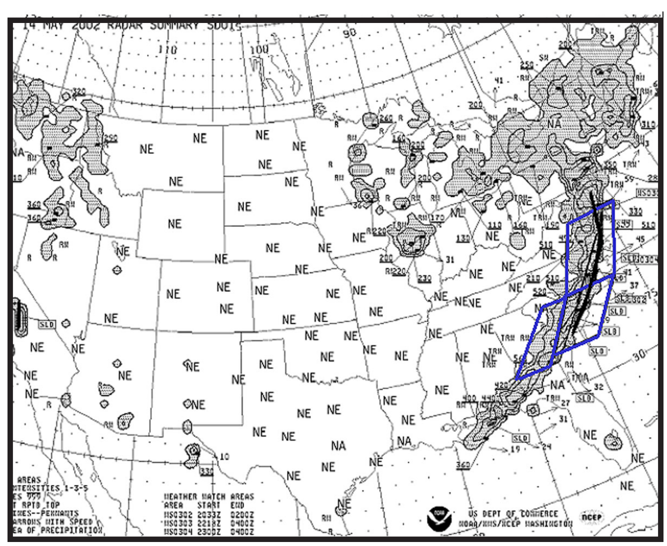

Figure 5-72. Radar Summary, 0115Z/14 May 2002.

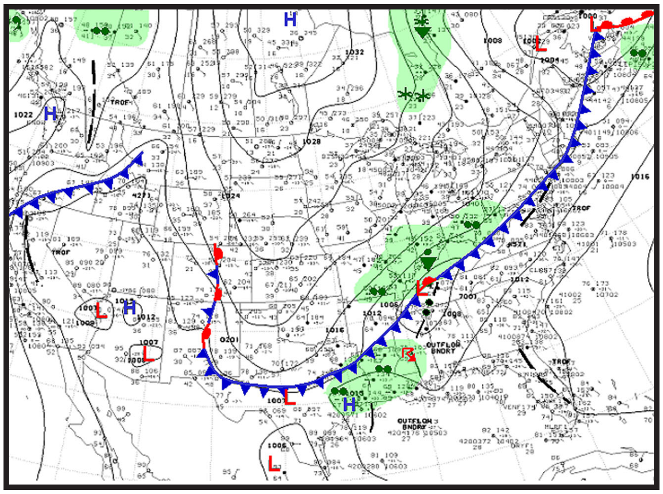

Figure 5-73. Surface, 2100Z/17 May 2002.

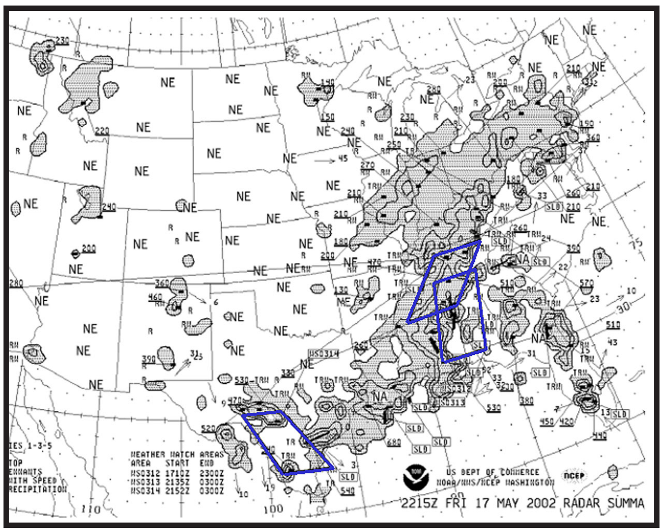

Figure 5-74. Radar Summary, 2215Z/17 May 2002.

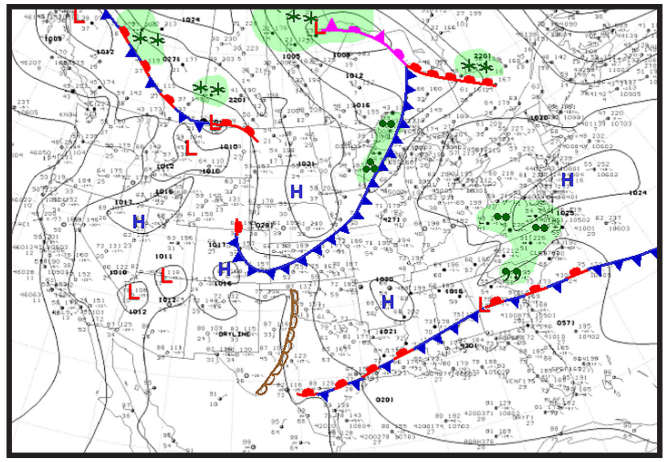

Figure 5-75. Surface, 2100Z/4 May 2002.

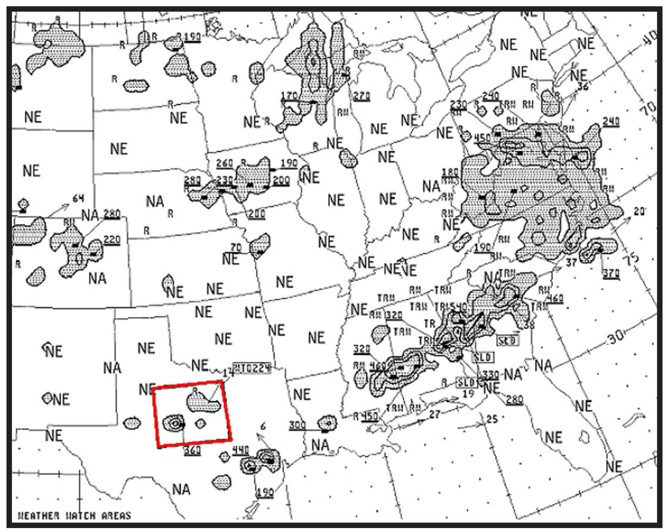

Figure 5-76. Radar Summary, 2215Z/4 May 2002.

Warm Frontal/Stationary Frontal Thunderstorms

Beginning in mid-spring and continuing through the summer months, cold frontal systems often become stationary and generally aligned east-to-west over the central and southern CONUS, as storm tracks shift northward into central Canada and subtropical ridging appears over the southern CONUS. Figures 5-75 through 5-81 show examples of warm or stationary frontal thunderstorms. In Figures 5-75 a stationary front is shown from southern Texas to the Atlantic Ocean. Thunderstorms have developed along the stationary front from Mississippi to South Carolina as depicted in Figure 5-76.

The satellite images, Figures 5-77 and 5-78, show east-to-west cloud systems and embedded convection associated with stationary fronts. One more example follows in Figures 5-79 through 5-81.

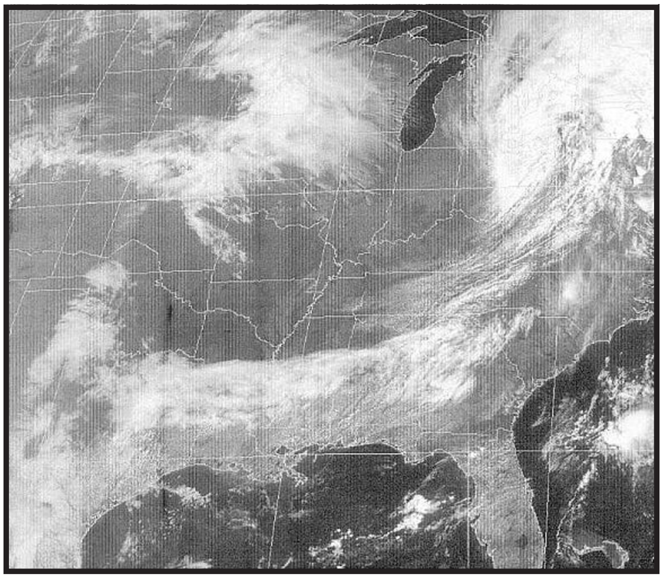

Figure 5-77. GOES E VIS, 1532Z/10 May 2000.

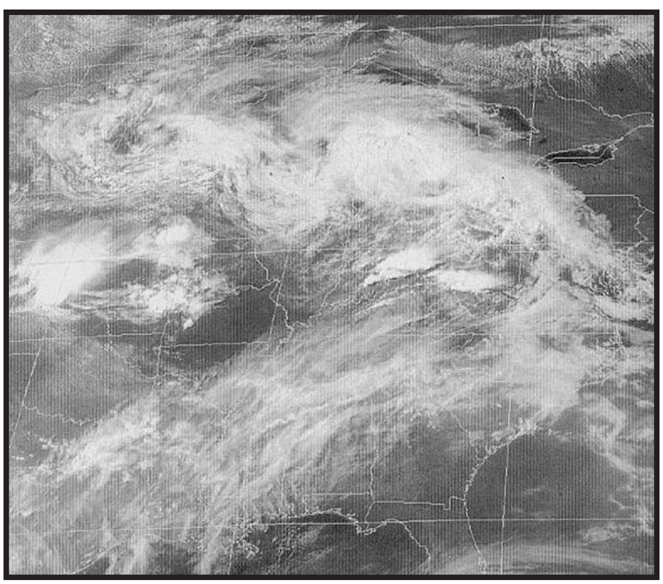

Figure 5-78. GOES E VIS, 2045Z/24 May 1998.

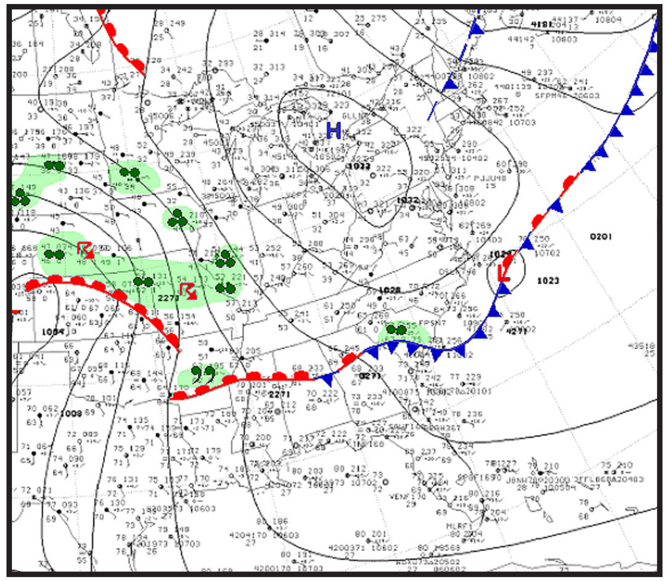

Figure 5-79. Surface, 1200Z/11 May 2002.

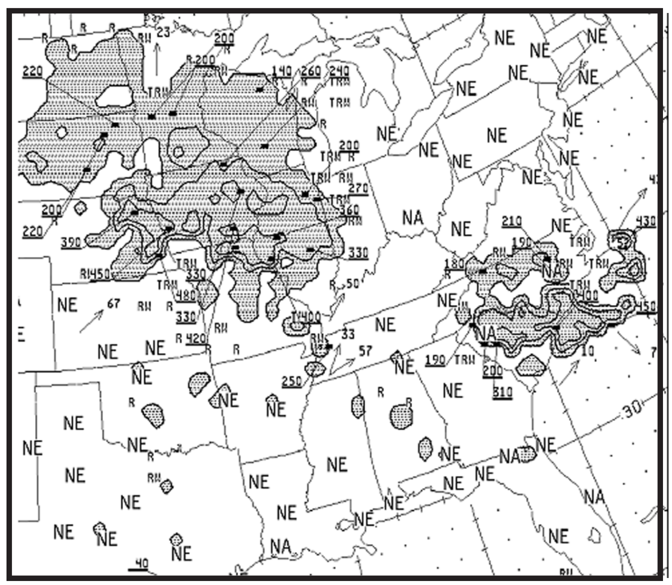

Figure 5-80. Radar Summary, 1415Z/11 May 2002.

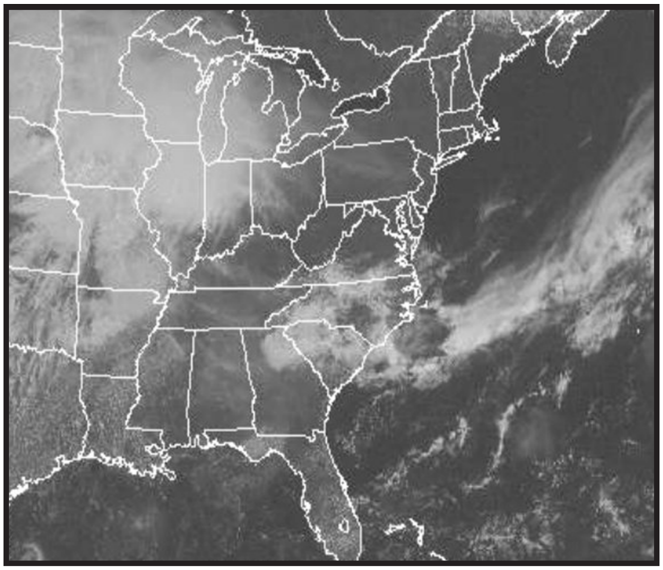

Figure 5-81. GOES E VIS, 1545Z/11 May 2002.

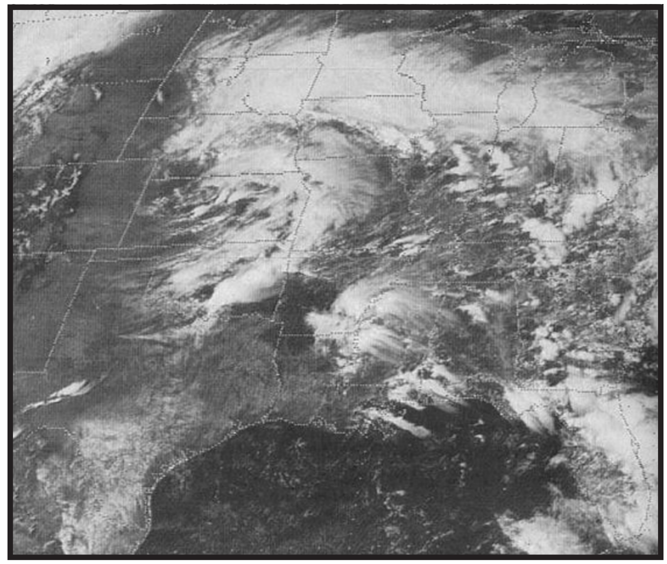

Figure 5-82. GOES E VIS, 2030Z/26 May 1982.

Air Mass Thunderstorms

By May, **non-frontal** thunderstorms occur often during the heating hours over the eastern CONUS, where air masses are moist and unstable. Surface triggers for convection and thunderstorm development are differential surface heating, convergence zones, orographic lifting, outflow boundaries, moisture axes and coastal sea breezes. In addition to these surface features, mid-level cold troughs and pockets help destabilize the middle and lower levels. These frequent disorganized thunderstorm cells/cluster occurrences are generally known as *air mass events*. Potential for severe thunderstorms is likely, especially when mid-level cold troughs/pockets exist which enhance destabilization. Air mass thunderstorms gradually dissipate throughout the evening hours, with the loss of surface heating. Air mass thunderstorms occur daily throughout the summer months. The visible satellite images, shown in Figures 5-82 through 5-85, illustrate various air mass events over the eastern CONUS. Figures 5-84 and 5-85 depict late spring/early summer events.

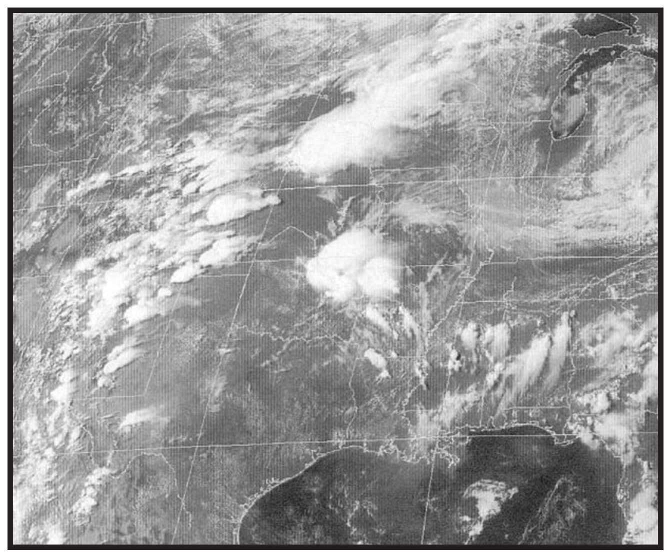

Figure 5-83. GOES E VIS, 2146Z/22 May 1999.

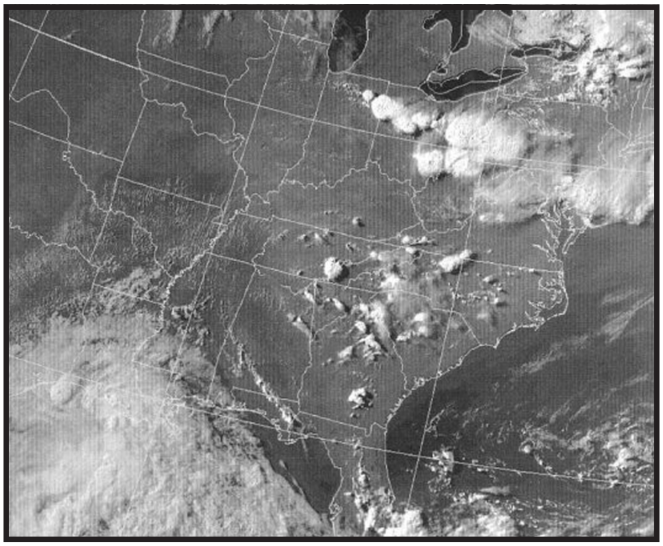

Figure 5-84. GOES E VIS, 2257Z/26 June 1998.

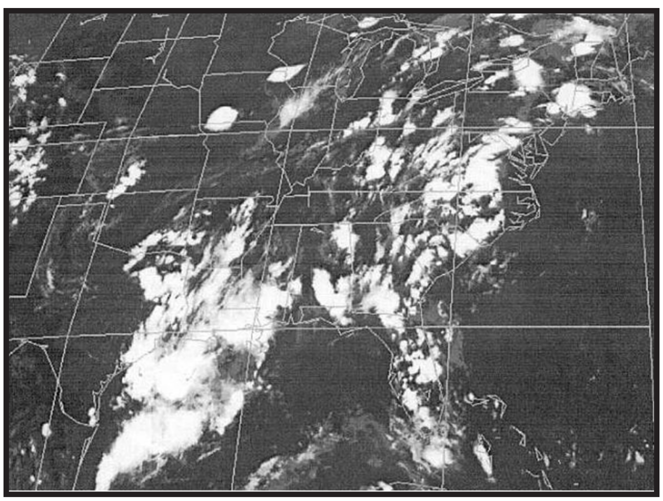

Figure 5-85. GOES E VIS, 1932Z/26 June 2002.

Sea Breeze Thunderstorms

The summer regime of sea breeze coastal thunderstorms during the heating hours begins in late April. This regime appears often along the Gulf of Mexico and Florida coastal areas, as long as the diurnal cycle is not interrupted by changes in the low-level air mass (i.e. fronts and troughs). Figures 5-86 through 5-89 illustrate four examples of Florida sea breeze events. In Figure 5-89, a late spring photo, sea breeze convection appears over southern Alabama to northern Florida. Sea breeze thunderstorm events along the Texas-to-Alabama Gulf Coast are generally summer regime events.

Depending on the direction of the low-level flow, a sea breeze will develop either on the east side and/or west side of the Florida peninsula. Thunderstorms develop quickly within the sea breeze convergence zone over

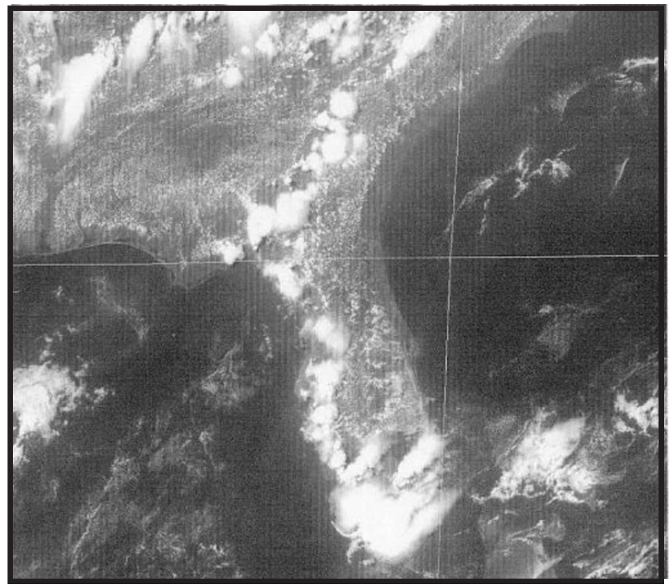

Figure 5-86. GOES E VIS, 1932Z/22 May 1999
Sea breeze thunderstorms are shown along the west coast of Florida.

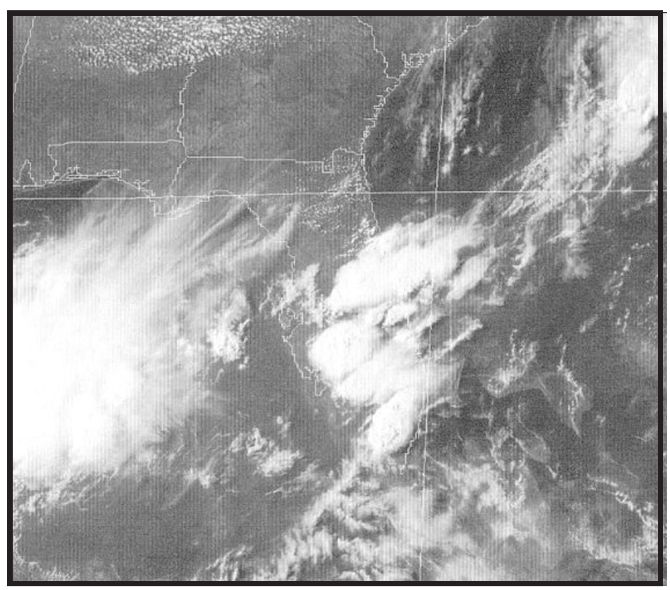

Figure 5-87. GOES E VIS, 2132Z/8 May 1999
Thunderstorms have developed within the interior areas of central Florida

the interior areas of the peninsula and move toward the coast as they mature. Predominate offshore wind flow would retard local sea breeze development. Undoubtedly, peninsula forecasters have good local rules for forecasting the location and onset of sea breeze thunderstorm activity.

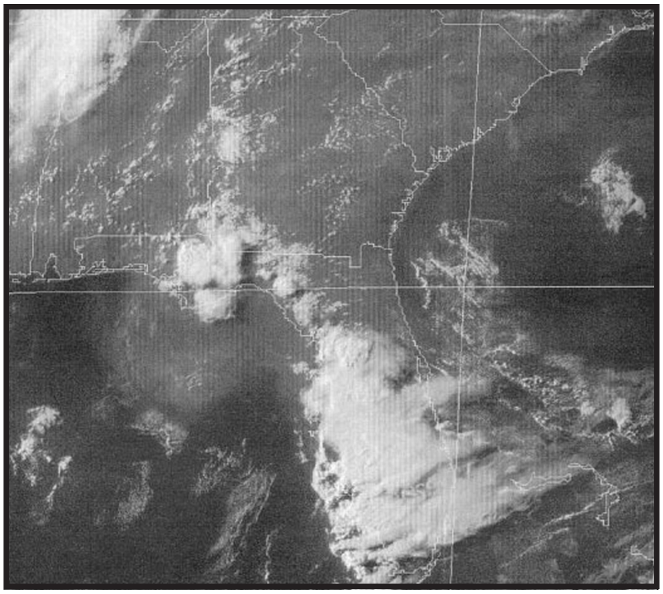

Figure 5-88. GOES E VIS, 2225Z/21 May 1999 Thunderstorms cover a large area of central and southern Florida. The Tampa-to-Orlando corridor is notorious for thunderstorm events.

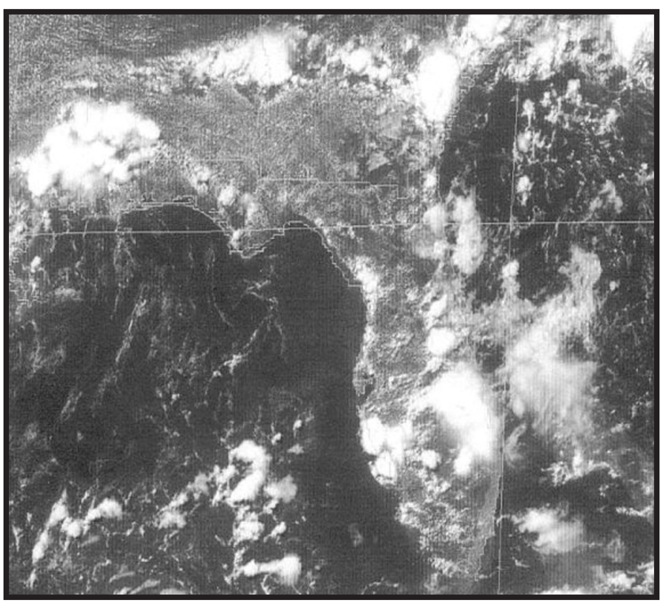

Figure 5-89. GOES E VIS, 1845Z/19 June 2001.

Land Breeze Thunderstorms

The low-level wind flow along the coastal area reverses at night and a land breeze regime becomes established. This regime occurs more often during the summer months. Land breeze thunderstorms develop offshore at night as winds from the cooler land surfaces flow to the warmer waters. These thunderstorms line up off shore parallel to the coastline but generally do not move inland until surface heating begins. The reversal from land to sea breezes squelches land breeze thunderstorms by mid-morning. No illustrations were available.

Thunderstorm Cirrus Plumes

Thunderstorm cirrus plumes can be used to determine the wind flow at the higher levels as shown in Figure 5-90. In this example the arrows mark the wind flow direction around a ridge.

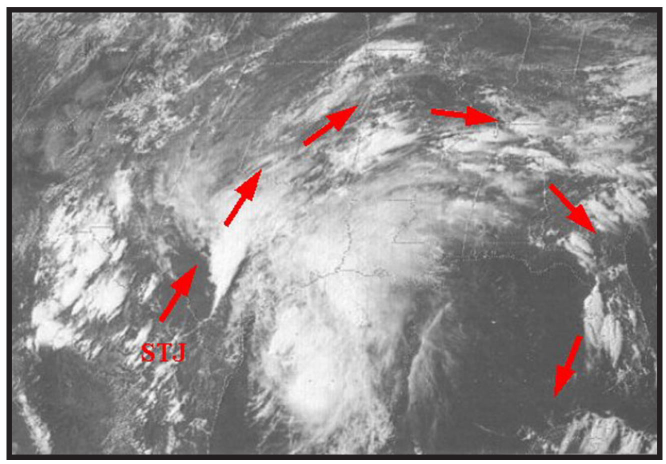

Figure 5-90. GOES E VIS, 2130Z/4 June 1981.

Upper Level Divergence (Satellite Interpretation)

Convection, especially severe convective weather, is frequently associated with a high-level divergence zone between the subtropical jet and the southern branch of the polar jet (Figure 5-91). Since these two jet streams are at different levels, it is often difficult to locate them both on the same constant pressure chart. The cirrus shield and bands shown in infrared photos are an excellent way to locate jet streams. During the dynamic spring

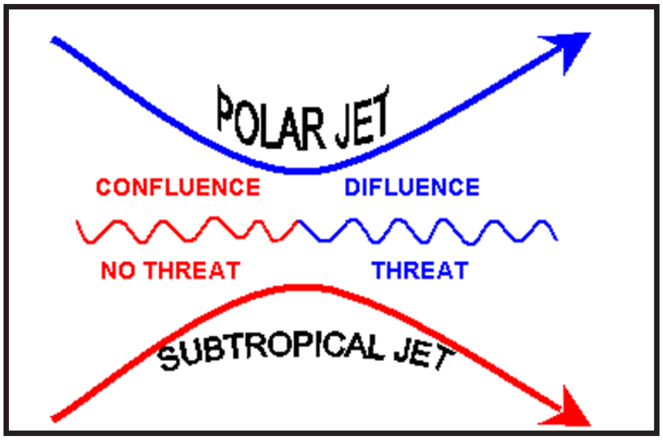

Figure 5-91. Threat/No Threat Areas.

season, the anticyclonic subtropical jet stream appears on the scene across the southern CONUS. Meanwhile, the cyclonic polar jet continues to be active over the central and northern CONUS. As shown in Figure 5-91, a difluent area is created between these two jet stream systems. Springtime large severe thunderstorm outbreaks generally occur with this regime; Figures 5-92 through 5-94 illustrate this principle.

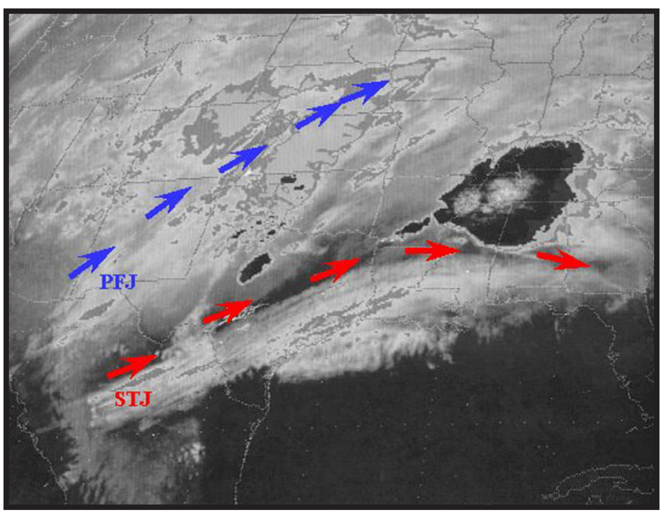

Figure 5-92. GOES E IR (MB), 0400Z/5 April 1983. Jet stream placement based on satellite interpretation. The subtropical jet is evident. The polar jet is placed where it enters the surge region of the comma cloud over the Great Plains.

Figure 5-93 depicts the satellite imagery seven and one-half hours later from Figure 5-92. The thunderstorm area over the eastern CONUS continues to grow through the nocturnal period.

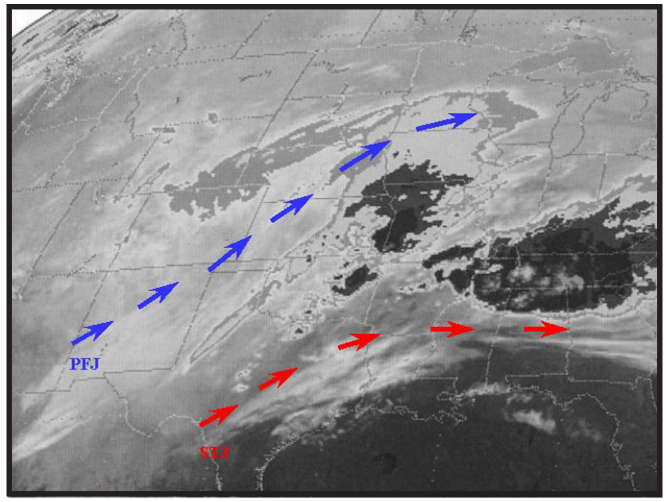

Figure 5-93. GOES E IR (MB), 1130Z/5 April 1983.

Figure 5-94 illustrates another example. In the figure, a large area of difluence between the polar and subtropical jets encompasses an area from the central plains eastward to the East Coast. Thunderstorms are visible from Oklahoma to the Great Lakes as noted by the arrows. The difluence/threat area shown in Figure 5-94 covers a large area; forecasters must still locate the most likely area where convection will fire (low-level moisture, instability, convergence, etc.) within these large areas of difluence.

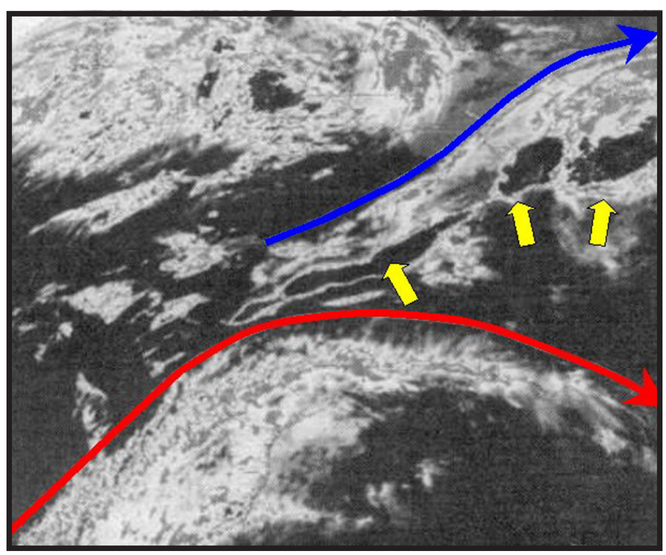

Figure 5-94. GOES E IR (MB), 2200Z/28 April 1981. It is difficult to see the political boundaries. The center of the photo is located over Kansas and Missouri. Arrows denote thunderstorm areas.

Tropical Storms

Officially, the tropical storm season begins on June 1 for the Atlantic Ocean and Gulf of Mexico. However, actual tropical storm occurrences are more likely to begin in late June and continue through the summer months.

Non-Convective Surface Wind Regimes (Notorious Wind Boxes) Early Spring

Great Lakes and the Appalachian Mountains Boxes

These two wind regimes occur occasionally during the early spring season and are included here since they may occur well into April on occasion. The prevailing wind direction in the Great Lakes and the Appalachian Mountains boxes is west-to-northwest. Figure 5-95 depicts the Great Lakes and Appalachian Mountain wind box regions affected by strong cold air advection (CAA) winds. When a large-scale cyclonic circulation occurs over the eastern CONUS, it would be difficult to discern between these two wind events.

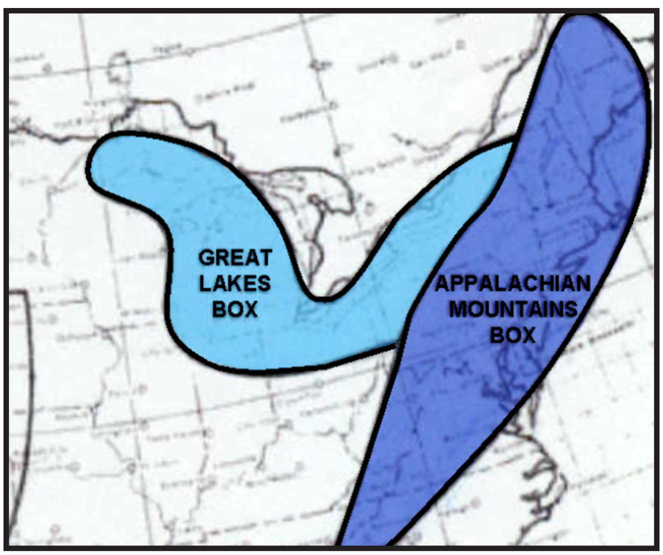

Figure 5-95. Great Lakes/Appalachian Mountain Wind Boxes.

Appalachian Mountains Box

The Appalachian Mountains Box occurs most often when strong cold fronts stretch along the mountains from New England to northwestern Georgia. Forecasters should look for tight pressure gradients and strong pressure rise/fall couplets. Several scenarios for strong Appalachian Mountain wind events are documented, but the most common pattern is shown in Figures 5-96 and 5-97. Often, the first indicators of strong cold air advection winds that will affect locations east of the mountains are along the Appalachian ridge line as the cold air rushes down the lee side.

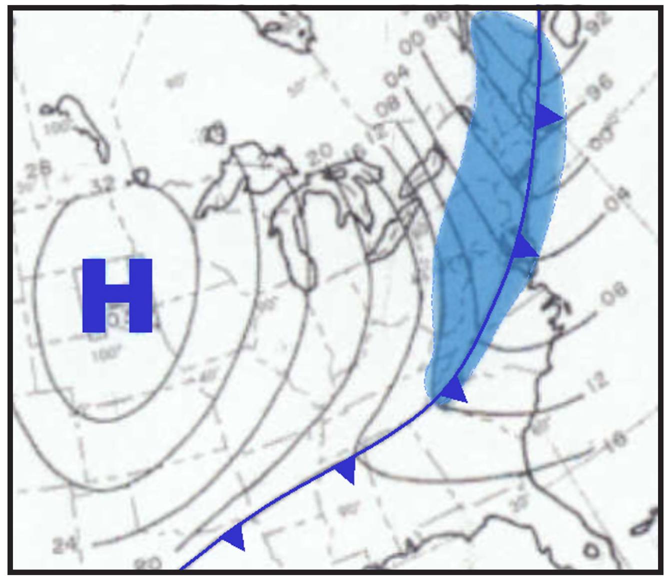

Figure 5-96. Appalachian Mountains Box.

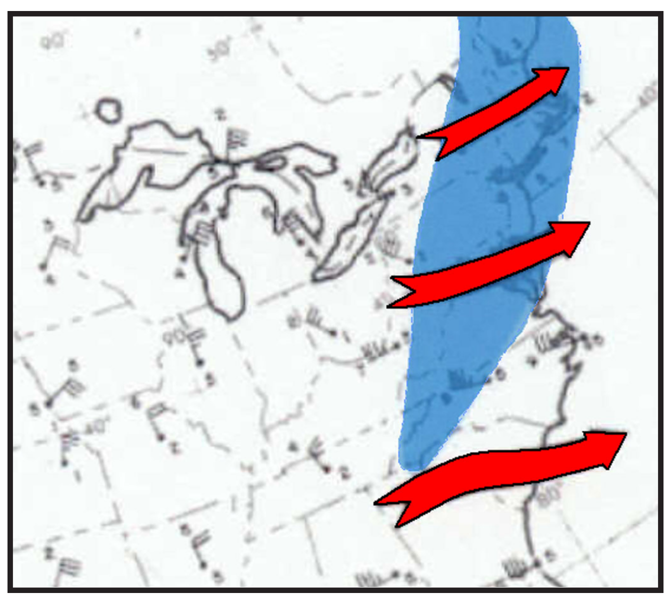

Figure 5-97. Appalachian Mountain Low-Level Winds - Example.

Figures 5-98 through 5-100 (12HR and 24HR forecasts) shows an example during early May where the Great Lakes and part of the Appalachian Mountain Boxes were affected by strong pressure gradients and strong CAA winds. Figure 5-98 depicts the 12-hour upper air forecast. A strong short wave is forecast over the Great Lakes region.

The related 12-hour surface forecast is shown in Figure 5-99. A tight north-south pressure gradient is shown across the Great Lakes. Additionally, strong thickness packing is forecast over the Great Lakes. Surface winds >35 knots occurred across the Great Lakes.

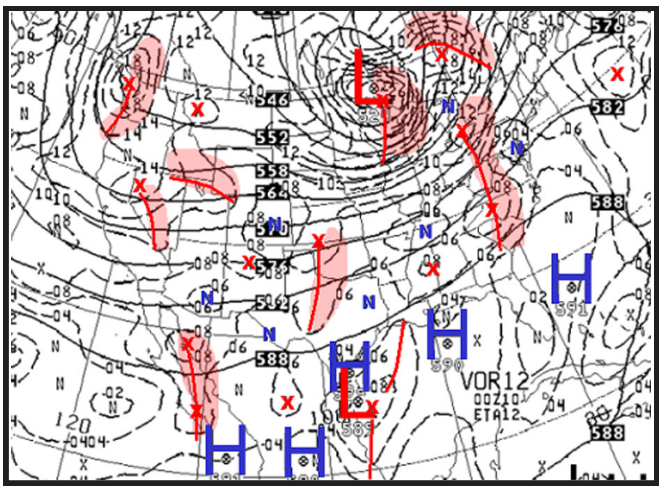

Figure 5-98. ETA 12HR 500MB HEIGHTS/ VORTICITY, 0000Z/10 May 2002.

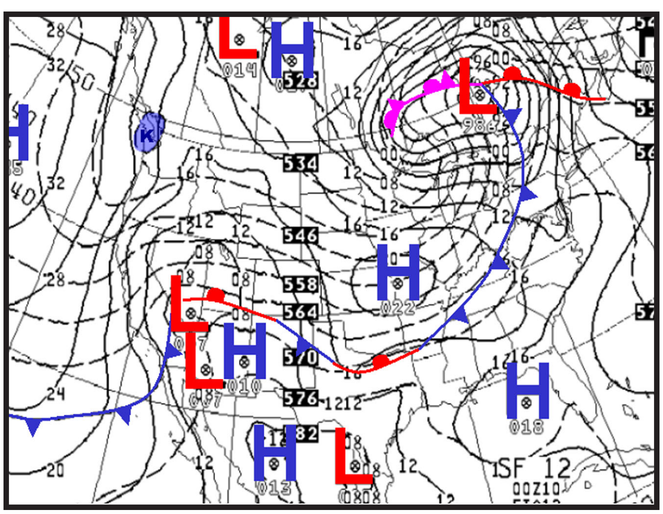

Figure 5-99. ETA 12HR MSL PRES/1000-500 THCKNS, 0000Z/10 May 2002.

The 24-hour forecast is depicted in Figure 5-100. The cold front is forecast to move into the Atlantic Ocean; the pressure gradient behind the front was sufficient to produce strong daytime surface winds within the Appalachian Mountain Box from Pennsylvania northeastward to Maine.

One more example is shown in Figure 5-101 that occurred in mid-May. A strong northeast-southwest pressure gradient that produced strong surface winds is shown over the northeastern CONUS.

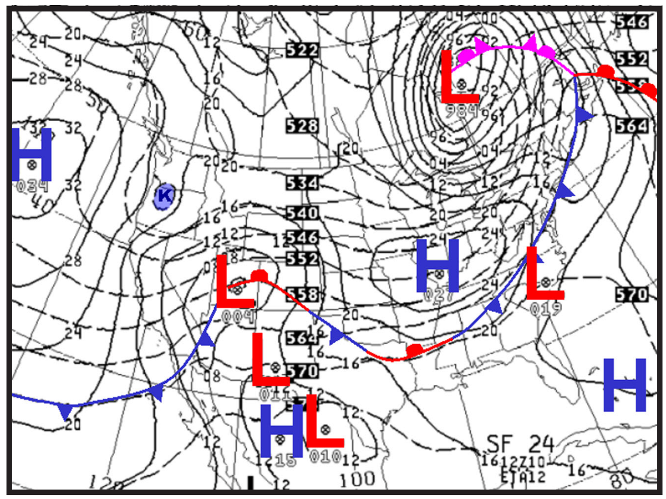

Figure 5-100. ETA 24HR MSL PRES/1000-500 THCKNS, 1200Z/10 May 2002.

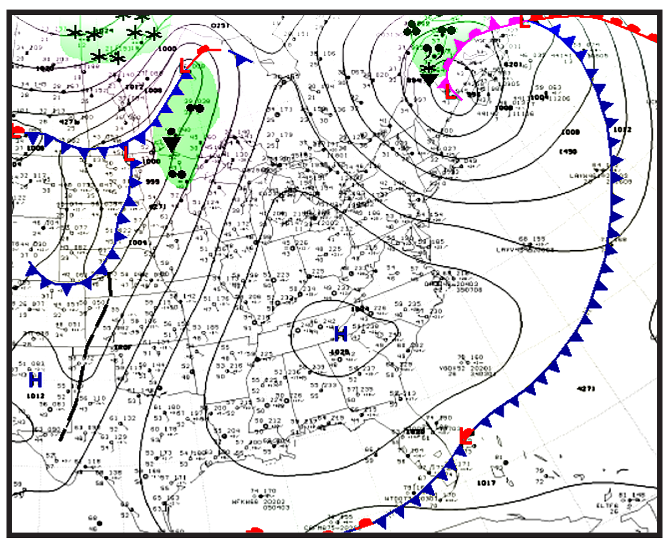

Figure 5-101. Surface, 0000Z/15 May 2002.

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